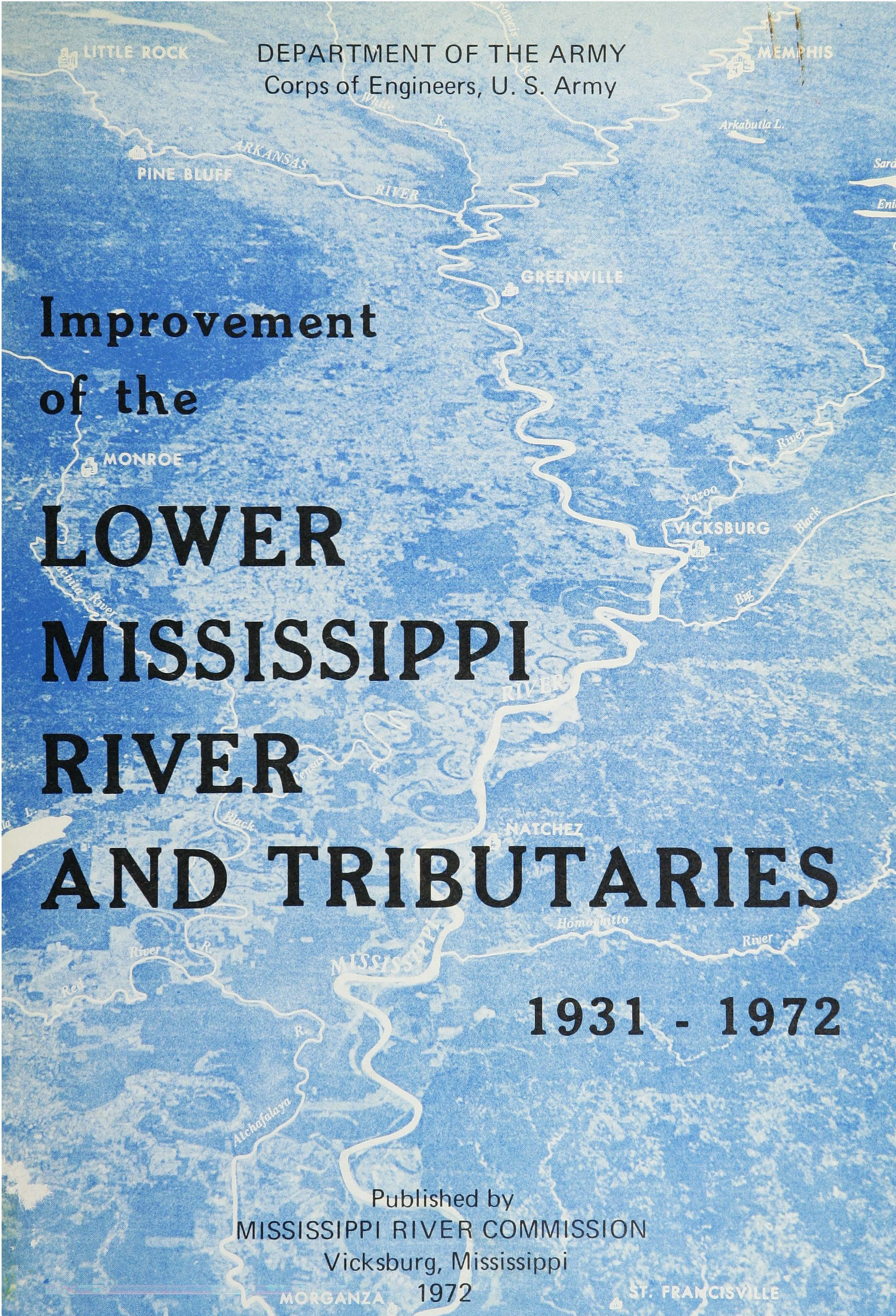
DEPARTMENT OF THE ARMY
Corps of Engineers, U. S. Army

Improvement of the LOWER MISSISSIPPI RIVER AND TRIBUTARIES

1931 - 1972



Published by
MISSISSIPPI RIVER COMMISSION
Vicksburg, Mississippi
1972

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **NOV 1972**	2. REPORT TYPE	3. DATES COVERED **00-00-1972 to 00-00-1972**

4. TITLE AND SUBTITLE **Improvement of the Lower Mississippi River and Attributes 1931-1972**	5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Army Corps of Engineers,Vicksburg District,4155 Clay Street,Vicksburg,MS,39183**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S) 11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**256**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

COVER

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Elevation 120 miles.

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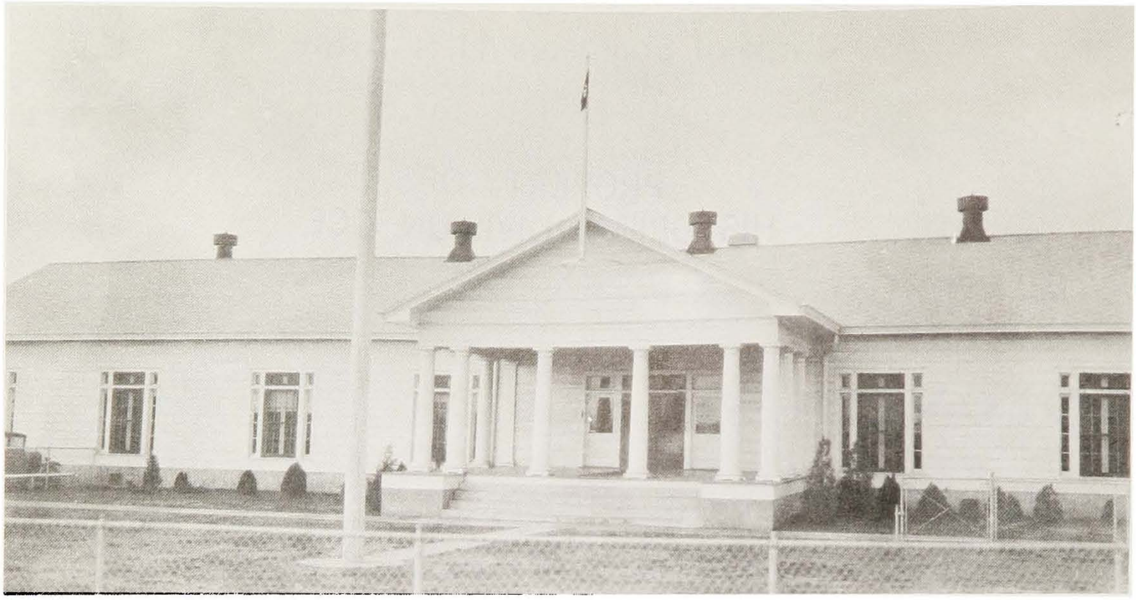
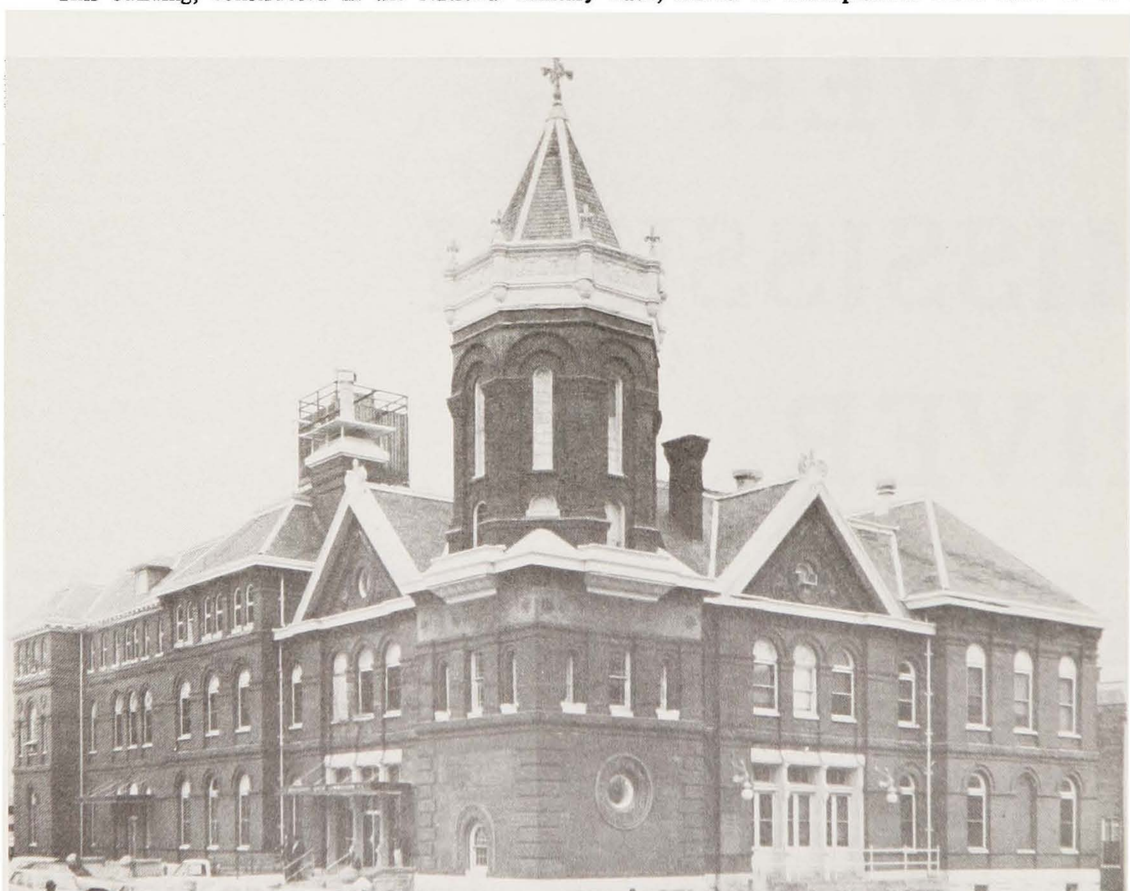


This building, constructed in the National Military Park, served as Headquarters from 1930 to 1944



The former U. S. Post Office Building in Vicksburg has served as Headquarters since 1944

Frontispiece. Headquarters buildings of the Mississippi River Commission, Vicksburg, Mississippi

FOREWORD

The three-volume comprehensive history, *The Improvement of the Lower Mississippi River for Flood Control and Navigation,* prepared under the direction of Brigadier General T. H. Jackson by Major D. O. Elliott, Corps of Engineers, traces the Mississippi River Valley's development from earliest times to the year 1931. The account by Brigadier General Harley B. Ferguson entitled *History of the Improvement of the Lower Mississippi River for Flood Control, 1932-1939* is less comprehensive, being devoted to a discussion of new steps taken to cure the river's ills by means of cutoffs and corrective dredging. The volume published on 1 June 1935, *Bank Protection on the Mississippi and Missouri Rivers,* prepared by Colonel T. H. Jackson, Corps of Engineers, centers on only one aspect of the improvement program.

Since 1931, the Mississippi River and Tributaries Project, authorized by Congress in 1928, has been modified and tremendously expanded by direction of Congress. Many betterments have been realized, and much has been learned about the river and how to control it. Important work lies ahead. However, it has seemed appropriate to prepare a record of the effort and accomplishment since 1931. This needed to be done while there are available key members of the staffs of the offices of the Mississippi River Commission and the U. S. Army Engineer Districts who have intimate knowledge of the project in the intervening years. The task of preparing this account was assigned to Norman R. Moore, a senior member of the planning staff of the Mississippi River Commission, whose knowledge of the project extends over the past 37 years.

This is a story of man's ingenuity in overcoming one of the great engineering challenges in our history, the control of the mighty Mississippi River. This is also an account of the work that has resulted in the development of the Lower Mississippi Valley as a vital, productive part of the United States. Reading this history should be interesting to engineers, economists, political scientists, and to the millions of Americans whose daily lives are affected by Old Man River.

CHARLES C. NOBLE
Major General, USA
President, Mississippi River Commission

Vicksburg, Mississippi
November 1972

ABOUT THE AUTHOR

Norman R. Moore is a native of Illinois and was graduated in 1925 from the University of Minnesota with a degree in Civil Engineering. His first professional experience was with the Pennsylvania Railroad. Mr. Moore left the railroad to become associated with the consulting engineering firm of Dayton-Morgan Engineering Company which was engaged in planning and design of flood control projects in the Miami Valley of Ohio. This activity was suspended because of the Depression. Mr. Moore then engaged in bridge engineering for the Ohio Department of Highways.

In 1934, initiation of planning for the Muskingum Flood Control Project in eastern Ohio offered the opportunity to further his interest in flood control engineering, and Mr. Moore accepted a position with the Zanesville District, Corps of Engineers. When work had advanced to the construction stage, he was assigned as Resident Engineer on Beach City Dam. At the end of the first construction season, he was loaned to the Vicksburg District to initiate planning for Sardis Dam, a project authorized by the Flood Control Act of 1936. He later accepted a permanent position with the Vicksburg District, which included the responsibility for the design of four Yazoo Basin headwater dams.

Mr. Moore retired from Government service in 1970 after serving six years as Chief of the Design Branch and fifteen years as Chief of the Engineering Division, in the Office of the President, Mississippi River Commission.

Active in civic matters pertaining to engineering, the author has served terms as National Director and as Vice-President of the American Society of Civil Engineers.

AUTHOR'S PREFACE

Elliott's history, *The Improvement of the Lower Mississippi River for Flood Control and Navigation,* published in 1932, is an account of the engineering history of the valley for about 100 years, including several years of engineering operations following passage of the Flood Control Act of 1928. Elliott divided his history into four periods: discovery and settlement; investigations and engineering operations by the Federal Government up to the creation of the Mississippi River Commission in 1879; Mississippi River Commission operations, 1879 to 1928; and engineering operations following the reorganization effected by the 1928 act. The work reported herein is an extension of Elliott's fourth period, including a description but omitting details of the cutoff construction included in Ferguson's history published in 1940 and projecting the history to mid-1972. Because few copies of the Elliott history are available for reference, portions of the Elliott account have been repeated in abbreviated form, where necessary to afford needed background.

Liberal use has been made of records of the Mississippi River Commission, the U. S. Army Engineer Waterways Experiment Station, and the Corps of Engineers District offices. These include congressional project documents, acts of Congress and reports of its committees, annual reports of the Chief of Engineers, and technical memoranda, many of them unpublished, covering tests and studies. The objective has been to be brief without leaving unanswered major questions that inevitably arise in discussing a project of this scope.

The advancement of the Mississippi River and Tributaries Project has enlisted the finest efforts of innumerable individuals, including, though not limited to, Congressional leaders, officers of the Corps of Engineers, civilian engineers, contractors, and local-interest leaders. Not a few have made outstanding contributions of an enduring character. It is unfortunately infeasible to attempt to single out individuals for special recognition in this history.

A similar situation exists with respect to acknowledgment by name of those individuals who contributed material for this account. An undertaking of this character calls for the cooperation of many persons. So many have responded generously to requests for information that it would be quite impracticable to list their names, not to say risky because of possible omissions. In lieu of such a listing, thanks are extended to all personnel of the several offices who have been so helpful. Two exceptions in the matter of names are justified. Mrs. Betty R. Johnson has searched for and made available the many needed documentary references among the voluminous historical records of the Mississippi River Commission library. Her efficient, tireless assistance is gratefully acknowledged. Special thanks and appreciation are also due Mrs. Eulanie M. Baker who, besides typing the manuscript, has so conscientiously applied her editorial ability and broad knowledge of report procedures of the Corps of Engineers in preparation of the final text.

The author alone is responsible for interpretations made, conclusions drawn, and any errors of omission or commission.

NORMAN R. MOORE
Fellow, American Society of Civil Engineers

Vicksburg, Mississippi
November 1972

TABLE OF CONTENTS

Chapter IV

PROJECT DESIGN AND CONSTRUCTION

Page

Chapter V

PROJECT EXPERIENCE

Chapter VI

OPERATION AND MAINTENANCE OF PROJECT FEATURES

Page

Chapter VII

PROJECT COSTS AND FUNDING PROCEDURES

Chapter VIII

PROJECT BENEFITS

Chapter IX

PLANNING FOR THE FUTURE

Appendix A

PRESIDENTS, MEMBERS, AND SECRETARIES OF THE MISSISSIPPI RIVER COMMISSION

INDEX

LIST OF FIGURES

Page

Page

LIST OF TABLES

CHAPTER I. THE MISSISSIPPI RIVER COMMISSION AND THE ADOPTED PROJECT

A history of the Federal project for improvement of the lower Mississippi River for flood control and navigation should begin with the Mississippi River Commission, the agency charged by Congress with prosecution of the project. When the act for control of floods on the Mississippi River and its tributaries, and for other purposes, was adopted in 1928, the Commission had been in existence for 49 years. Its creation by an act of Congress in 1879 was, in part, due to public recognition of the urgent need for improving the Mississippi River for navigation and flood control, and to a growing belief that a solution at a reasonable cost was possible. Experience had also shown the need to coordinate engineering operations through a centralized organization.

As constituted, the Commission consisted of seven members appointed by the President of the United States. Three of the Commissioners were to be selected from the Corps of Engineers, U. S. Army; one, from the U. S. Coast and Geodetic Survey; and three, from civil life. Two of the three from civil life were to be civil engineers. The law provided that the President of the Commission would be one of the members appointed from the Corps of Engineers, and authorized the detail of an Engineer officer to serve as Secretary of the Commission. Section 4 of the act prescribed the duties of the Commission as follows:

> * * * It shall be the duty of said Commission to take into consideration and mature such plan or plans and estimates as will correct, permanently locate, and deepen the channel and protect the banks of the Mississippi River; improve and give safety and ease to the navigation thereof; prevent destructive floods; promote and facilitate commerce, trade, and the postal service; and when so prepared and matured, to submit to the Secretary of War a full and detailed report of their proceedings and actions, and of such plans with estimates of the cost thereof, for the purposes aforesaid, to be by him transmitted to Congress: Provided, That the Commission shall report in full upon the practicability, feasibility, and probable cost of the various plans known as the jetty system, the levee system, and the outlet system, as well as upon such others as they deem necessary. * * *

The Commission as thus established in 1879 was an executive body reporting to the Secretary of War, and its President was its administrative officer, who issued orders to subordinate operating districts, subject to approval of the Commission when it was in session. The basic act did not authorize construction of navigation or flood control works, but limited the activities of the Commission to completion of those surveys of the Mississippi River between its headwaters and the Head of Passes that were in progress at the time of passage of the act, and to the making of such additional surveys, examinations, and investigations of the river and its tributaries as might be deemed necessary by the Commission to carry out the objectives of the act. Thus the Commission's jurisdiction with reference to surveys and investigations included the entire Mississippi River above the Head of Passes, and also the tributaries of the Mississippi insofar as might be necessary.

In February 1880, less than 8 months following its establishment, the Commission made its initial report, which was concerned with the reach of river extending from Cairo to the Head of Passes. Broadly, its recommendations followed general plans proposed by a Board of Engineers that had been appointed in 1878 with instructions to report upon the improvement of low water navigation in the Mississippi and Missouri Rivers, and to consider the effects of a permanent levee system on the lower river upon navigation and flood control. The second Commission report, submitted in January 1881, covered the upper Mississippi from the Falls of St. Anthony to the Missouri River. A third report, made in November 1881, was concerned with the reach of the river from the mouth of the Missouri to the mouth of the Ohio River.

Operations of the Engineer Department of the Corps of Engineers in the Alluvial Valley of the Mississippi River did not end upon establishment of the Mississippi River Commission. Engineering operations in the valley beyond the Commission's jurisdiction (for example, navigation improvements on the tributaries) were the duty of the Engineer Department. The result was a dual engineer organization in the valley. By 1882, the Commission had divided the reach from Cairo to Head of Passes into four operating districts, and later created a Dredging District which was charged with dredging operations under Commission jurisdiction.

The River and Harbor Act of March 1881 appropriated $1,000,000 for Commission operations, and also provided for extension of the Commission's jurisdiction to the tributaries insofar as was necessary, in the Commission's judgment, for general and permanent improvement of the river. A second extension, made by the River and Harbor Act of 1882, provided for improvements of certain harbors and rectification of the Red and Atchafalaya Rivers at the mouth of Red River. The act of 1896 provided for maintenance of a navigable channel, 250 feet wide and 9 feet deep, below Cairo. The act of 1906 further expanded the jurisdiction of the Mississippi River Commission by authorizing the construction, under its jurisdiction, of levees between the Head of Passes and Cape Girardeau, Missouri, thus extending the Commission's responsibility for levees above Cairo to the head of the St. Francis Basin. The act of 1913 still further extended the Commission's jurisdiction to Rock Island, Illinois, with certain restrictions. This extension gave the Commission jurisdiction for levee construction over the reach from Rock Island to the Head of Passes, and jurisdiction for navigation improvements for rivercraft below Cairo. Since little dredging was needed for such navigation below Baton Rouge, the dredging operations under the Commission's control were, in general, limited to the reach of river between Cairo and Baton Rouge.

The River and Harbor Act of 1916 extended the jurisdiction of the Mississippi River Commission to include the Ohio River from its mouth to the mouth of the Cache River, and the Arkansas River from its mouth to the Lincoln-Jefferson County line. The Flood Control Act of 1917 further extended the Commission's jurisdiction to include the watercourses connected with the Mississippi River to the extent necessary to exclude floodwaters from the upper limits of any delta basins. In addition, this legislation introduced a policy of cooperation by local interests in requiring them to contribute to levee construction and repair costs not less than one-half of the sum allotted by the Commission for such work. The act also required local interests to provide levee rights-of-way free of cost to the United States, and required levee districts to maintain levees constructed for flood control under authority of that act.

The River and Harbor Act of 1922 extended the jurisdiction of the Commission, for purposes of levee protection and bank protection, to tributaries and outlets of the Mississippi River between Cairo and the Head of Passes insofar as those tributaries and outlets were affected by floodwaters of the Mississippi River. The Flood Control Act of 1923 provided that funds thereafter appropriated under authority of that act and which might be allotted to works of flood control could be expended upon any part of the Mississippi River between Head of Passes and Rock Island, and upon tributaries and outlets as they might be affected by floodwaters of the Mississippi.

Thus, in the first 49 years following its inception, the Mississippi River Commission had become the central agency for river improvement in the lower valley. An extensive basic-data-collection program had been established. Improvements in engineering and construction procedures, including channel maintenance by means of hydraulic dredges, had been developed. Levees were looked upon as the sole line of defense, and a system of levees had been constructed. The Commission's duties had been expanded to include flood control in addition to navigation, and the jurisdiction of the Commission had been

extended on the main stem and the tributaries. The principle of participation in costs by local interests had been adopted.

The great flood disaster of 1927 (see figure 1) forced a reappraisal of the "levees only" philosophy of flood control. Before the flood had passed, President Coolidge directed the Mississippi River Commission to report on special problems to be solved as part of a comprehensive plan for Mississippi River flood control. The Chief of Engineers, U. S. Army, was also requested to submit such a report. More than 300 other plans were submitted to the Committee on Flood Control of the House of Representatives. However, congressional consideration centered upon a plan submitted by the Mississippi River Commission and one submitted by Major General Edgar Jadwin, Chief of Engineers, which became known as the Jadwin Plan. The two plans were similar in many respects and were in general agreement as to engineering principles. The differences were principally those of capacities and amounts. The House Committee on Flood Control made an extensive investigation and heard the testimonies of a great many witnesses, recording more than 5,000 pages of testimony. The Jadwin Plan was adopted as the basis for the Flood Control Act of 15 May 1928. The act designated a three-member Board to make a comparative study of the Jadwin and Commission plans. This Board reported to the President in August 1928. Its findings supported the adopted plan and recommended no changes.

Hence, the genesis of today's project is the engineering plan described in the Jadwin report of 1 December 1927, which was printed as House Document No. 90, 70th Congress, 1st session (see figure 2). This plan contemplated the control of a much greater flood than had formerly been thought possible. It limited the amount of floodwater carried in the main river to its safe capacity and provided for lateral floodways to pass the surplus. These floodways were from Birds Point to New Madrid; from the Arkansas River through the Boeuf Basin to the Red River; and from the Red River through the Atchafalaya Basin to the Gulf of Mexico. Provision also was made for a controlled spillway at or near New Orleans (see figure 3). The plan provided for raising and strengthening the levees between Cape Girardeau and the Head of Passes; for revetment of caving banks; and for improved navigation channels for river traffic to be obtained by dredging and training works, where necessary, between Cairo and New Orleans. The sum of $325,000,000 was authorized to be appropriated for the additional construction. In adopting this plan by the act of 15 May 1928, Congress authorized it to be prosecuted by the Mississippi River Commission under the direction of the Secretary of War and the supervision of the Chief of Engineers, thereby giving the Chief of Engineers authority to plan and direct the work. Subsequent to the act of 1879, legislation had given the Chief of Engineers and the Secretary of War veto power, but not initiative authority.

Section 2 of the 1928 act declared it to be the sense of Congress that the principle of local contribution toward the cost of flood control work, which had been incorporated in all previous national legislation on the subject, was sound. As a full compliance with this principle and in view of the great expenditure theretofore made by the local interests in the Alluvial Valley of the Mississippi River for protection against floods of that river, in view of the extent of national concern in the control of these floods in the interests of national prosperity, the flow of interstate commerce, and the movement of the United States mails, and in view of the gigantic scale of the project, involving floodwaters of a volume and flowing from a drainage area largely outside the states most affected, far exceeding those of any other river in the United States, no local contribution to the project thereby adopted was required. However, section 3 of the 1928 act stipulated that no money appropriated under authority of the act should be expended on construction of any item of the project until the States or levee districts have given assurances satisfactory to the Secretary of War that they will (a) maintain all flood control works

after their completion, except controlling and regulating spillway structures, such maintenance normally to include cutting grass, removing weeds, local drainage, and minor repairs of main river levees; (b) agree to accept all land acquired for flowage, to be turned over to them without cost; and (c) provide without cost to the United States all rights-of-way for levee foundations and levees on the main stem of the Mississippi River between Cape Girardeau, Missouri, and the Head of Passes.

The act further declared that the United States would provide flowage rights for additional destructive floodwaters that would pass by reason of diversion from the main Mississippi River channel, and stipulated that if execution of the flood control plan results in benefits to property, those benefits should be taken into consideration to the extent of reducing the amount of compensation to be paid. Provision was made for preparation of maps required in furtherance of the project, and for completion of the Mississippi River flood control works previously authorized but not included in the project. These works included levees on the main stem between Rock Island and Cape Girardeau, and on the outlets and tributaries of the Mississippi River between Rock Island and Head of Passes insofar as they are affected by Mississippi River backwater. For these works, it was stipulated that the States or levee districts should provide rights-of-way, should contribute one-third of the construction cost, and should maintain the levees after completion, all in conformity with prior directives of Congress.

Finally, the 1928 act prescribed the duties of the Mississippi River Commission. Summarizing section 8 of the act, they were as follows: (a) the Commission is to perform such duties as the Secretary of War and the Chief of Engineers direct; (b) the Commission is to make inspection trips and hold public hearings on these trips; and (c) the President of the Commission is the executive officer thereof. Pursuant to (a) above, the Secretary of War and the Chief of Engineers issued a directive on 14 November 1928 setting forth the following functions and agencies:

a. Making the inspection trips and holding the public hearings described under section 8 of the act approved 15 May 1928.

b. Recommendation of the policy for the development of the details of the project adopted by law.

c. Recommendation of the policy for carrying out the work under the adopted project.

d. Consideration and recommendation of the general character and types of work to be used in construction under the adopted project.

e. Recommendation annually of the program of work to be undertaken during the following fiscal year.

f. Recommendations upon any matters authorized by law.

g. The Executive Officer of the Commission and the Engineer Districts of the Mississippi Valley are designated as the agencies for carrying out the project.

Under the instructions, the President of the Commission is the Executive Agency charged with execution of the flood control project. The President of the Commission reports to the Chief of Engineers. The three Mississippi River Commission districts report direct to the President of the Commission. The functions of the Commission itself are advisory.

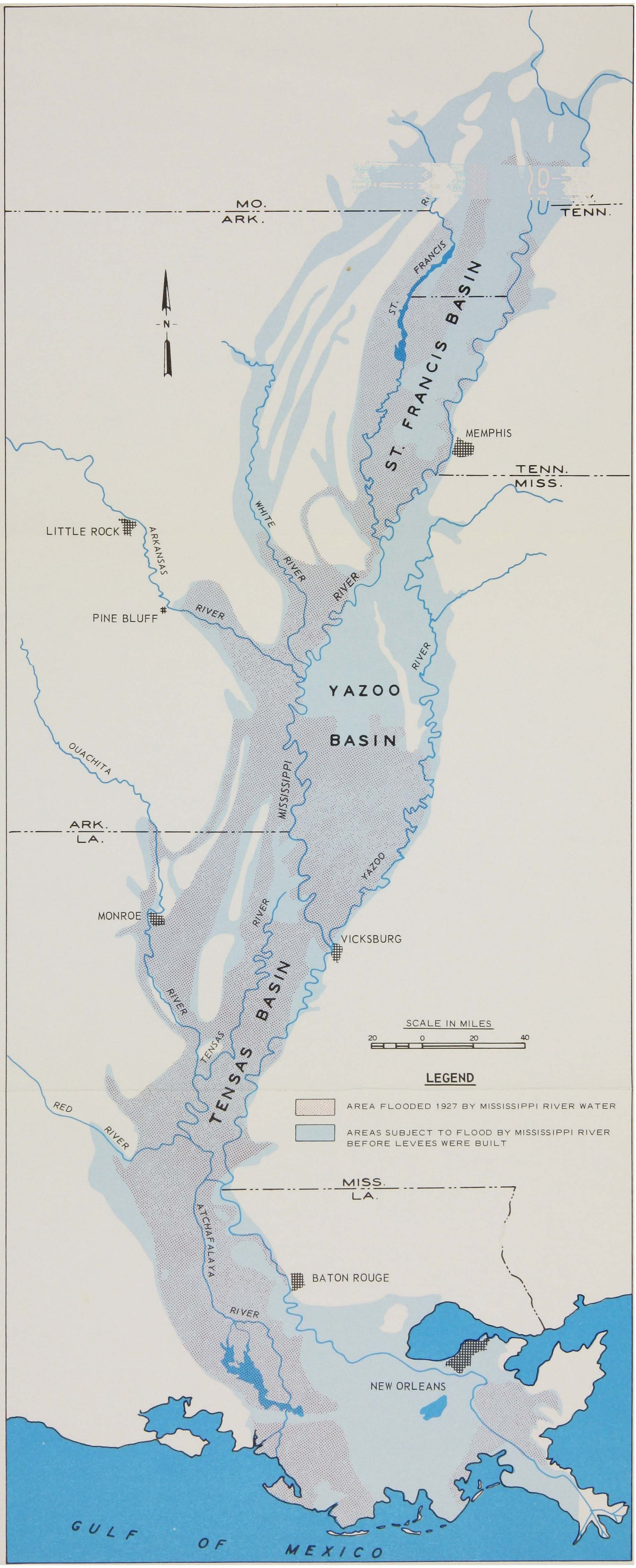


Figure 1. Alluvial Valley of the Mississippi River, showing areas flooded in 1927

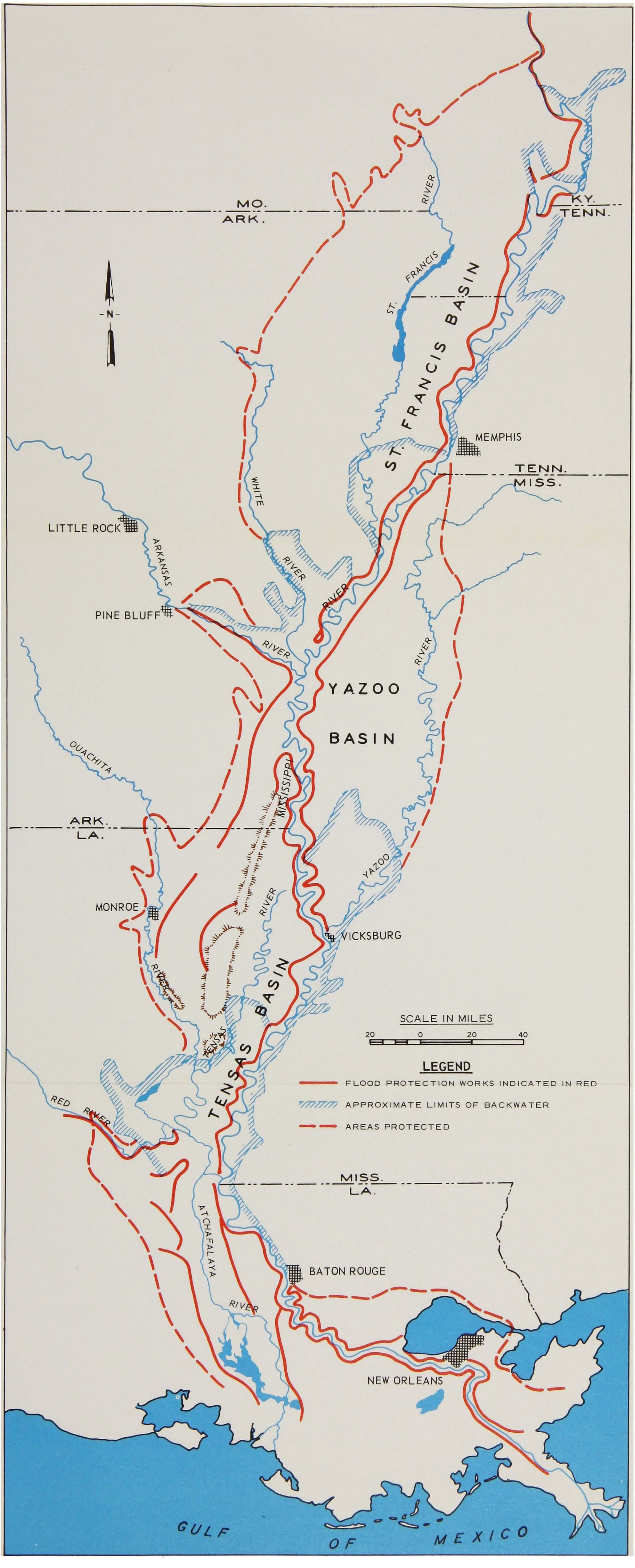
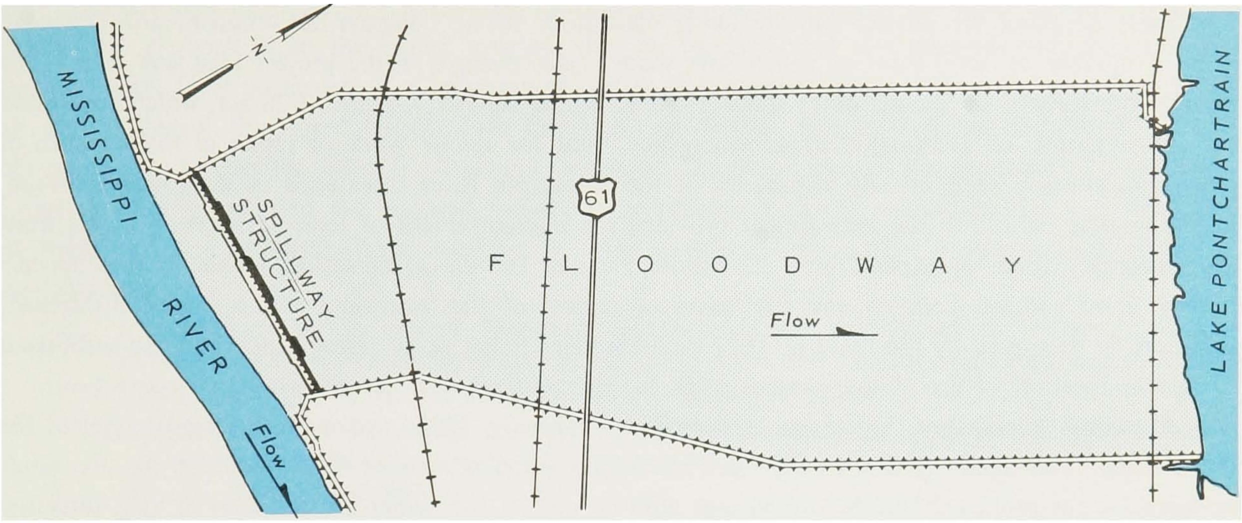


Figure 2. Alluvial Valley of the Mississippi River, showing Jadwin Plan of 1 December 1927 for flood control



PLAN

SCALE IN MILES

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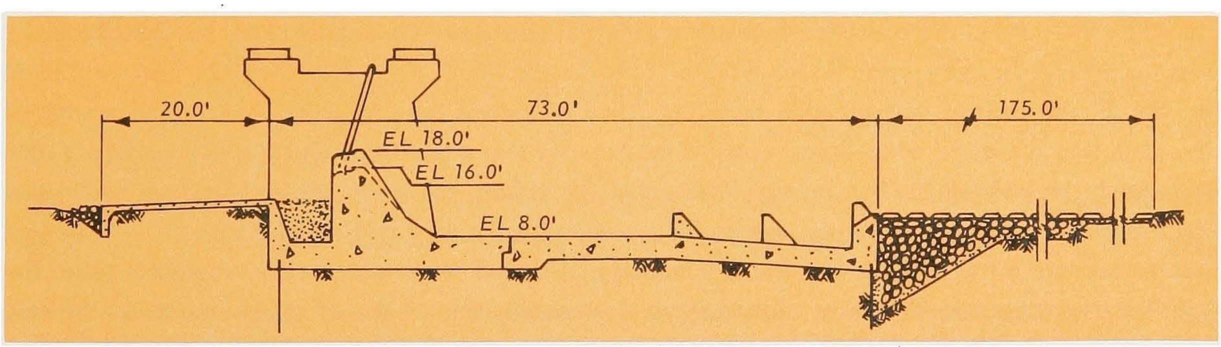

SECTION THROUGH SPILLWAY

Figure 3. Bonnet Carré Floodway and Spillway

CHAPTER II. PROJECT EXPANSION SINCE 1931 THROUGH CONGRESSIONAL ACTION AND DEVELOPMENT OF WATER AND RELATED LAND RESOURCES

Project Expansion Through Congressional Action

Since adopting the project for the lower Mississippi River, Congress has modified and expanded it by a number of acts, some of which have made major changes in the project plan and scope. The initial modification, by the act of 19 June 1930, amended section 7 of the 1928 act, which authorized the appropriation of $5,000,000 as an emergency fund for rescue work or repair or maintenance of any flood control work on any tributaries of the Mississippi River threatened or destroyed by flood, including that of 1927. The amendment provided for reimbursement of levee districts or others from the emergency fund for expenditures theretofore incurred for the construction, repair, or maintenance of any flood control work on any tributaries or outlets of the Mississippi that might be threatened, impaired, or destroyed by the flood of 1927 or subsequent flood, or by caving banks, and also authorized change in location of any flood control work in order to provide the contemplated protection.

A second amendment, by an act approved 15 February 1933, exempted the lands acquired for the Bonnet Carré Spillway and Floodway from the provision of section 4 of the 1928 act that lands acquired for the project should be turned over without cost to the ownership of States or local interests. It also made provision for grants to utilities for crossings of these facilities. This was followed by the act of 23 April 1934, which provided for reimbursement of States or local levee districts for the costs of levee rights-of-way or easements for the building of levees for which the United States was responsible under the 1928 act, regardless of whether the States or local levee districts had furnished such rights-of-way in the past. None of these acts made any additional monetary authorization.

The 1927 flood demonstrated that the capacity of the leveed channel of the lower Mississippi River was inadequate to carry great floods without considerable increases in levee heights. The plan adopted by the Flood Control Act of 1928 therefore relied on lateral floodways to divert excess waters from the main leveed channel when flows exceeded the capacity that would be available after making a moderate increase in levee heights. The Jadwin Plan called for raising the levee grade 3 feet on both sides of the Mississippi below the Arkansas, except for a section on the west side near Cypress Creek. This section was to become a fuseplug for the Boeuf Floodway, designed to crevasse in the event of a major flood, and thereby cause the floodway to operate as a diversion channel for all excess waters in the middle section of the Mississippi River. Levees were to be constructed on each side of the Boeuf River bottom, where natural ridges would not serve, from the Cypress Creek levee to backwater in the lower Tensas Basin. The plan was that the floodway would utilize lands that had historically been inundated in great floods, without reducing their existing protection.

Although the United States was to provide flood rights in the floodway for additional floodwaters that would pass by reason of diversion from the main stem of the river, the position was taken that a natural floodway existed by way of the Tensas Basin, and that, until the United States passed additional floodwaters down the floodway, no legal obligation existed. No compensation was paid to landowners except where the protection they previously enjoyed was or would be reduced by lowering of the levees under the plan. But obviously, landowners would not assent to use of their lands for floodway purposes without compensation.

In 1934, bills were introduced in Congress, having as their objective the elimination from the project

of provisions for construction of the Boeuf Floodway, as well as the designation of a portion of the west-bank levee as a fuseplug section. On 12 February 1935, pursuant to a resolution of the Committee on Flood Control of the House of Representatives, the Chief of Engineers submitted a supplemental report in which he recommended several modifications of the adopted project. These modifications were substantially as recommended by the Mississippi River Commission in an accompanying report. The new plan took into consideration the advantages of future improvement in flood-channel capacity that was anticipated to result from the cutoff program then in progress, and also probable reduction of crest flows to result from construction of tributary reservoirs. Both reports were published as House Committee on Flood Control Document No. 1, 74th Congress, 1st session, and formed the basis for S 3531, a bill introduced by Senator John H. Overton (Louisiana). The Flood Control Act approved 15 June 1936 ("Overton Act") modified the adopted project in accordance with the recommendations of the Chief of Engineers in Committee Document No. 1, with additional stipulations making up the following modifications:

a. Abandonment of the Boeuf Floodway and substitution therefor of the narrower Eudora Floodway, to be formed by constructing levees from the vicinity of Eudora east of Macon Ridge into the Red River backwater, with a control structure at its head.

b. A back protection levee from the head of the Eudora Floodway north to the Arkansas River, so located as to afford adequate space for the floodwaters without endangering the levees on the east side of the river.

c. Maintenance of the existing river levees between the head of the Eudora Floodway and the northern junction with the protection levee at the 1914 grade and section, except in front of densely populated areas as a part of a ring levee.

d. Construction of a floodway extending from the Mississippi River north of Morganza to the Atchafalaya River backwater, with a control structure at its head, in lieu of the East Atchafalaya Floodway (see figure 4).

e. Raising and enlarging the levees from the head of the Morganza Floodway to the head of the Atchafalaya River and down the east bank of the Atchafalaya River to an intersection with the west protection levee of the Morganza Floodway to 1928 grade and section.

f. Immediate completion of the Atchafalaya Basin guide levees to afford full protection to all lands outside these levees.

g. Construction of an additional outlet to the Gulf of Mexico west of Berwick (Wax Lake Outlet).

h. Improvement of the discharge capacity of the leveed channel of the Atchafalaya River and its outlets.

i. A 6-year program for the improvement and regularization of the Mississippi River including continued maintenance of the navigation channel, and additional work along the main river below the mouth of the Arkansas River in the form of cutoffs, other dredging, and other works, with the specific purpose of increasing its discharge capacity, which work would require the replacement or extension of some revetments.

j. Flood control of the St. Francis and Yazoo Rivers, subject to the furnishing of assurances of local cooperation, with provisos that the Yazoo River reservoirs could be located by the Chief of Engineers in his discretion, and that he might substitute levees, floodways, or auxiliary channels, or any or all of them, for any or all of the seven detention reservoirs recommended in his report of 12 February 1935; and further, to permit the modification of the St. Francis River Project, as recommended in his report, to include construction of a detention reservoir, provided that the estimated cost of the project to the United States is not increased by reason of the detention reservoir.

k. A system of levees for protection of the White River backwater area, subject to the furnishing of assurances of local cooperation that local interests would provide all rights-of-way necessary for construction of the project, provide drainage facilities made necessary by construction of

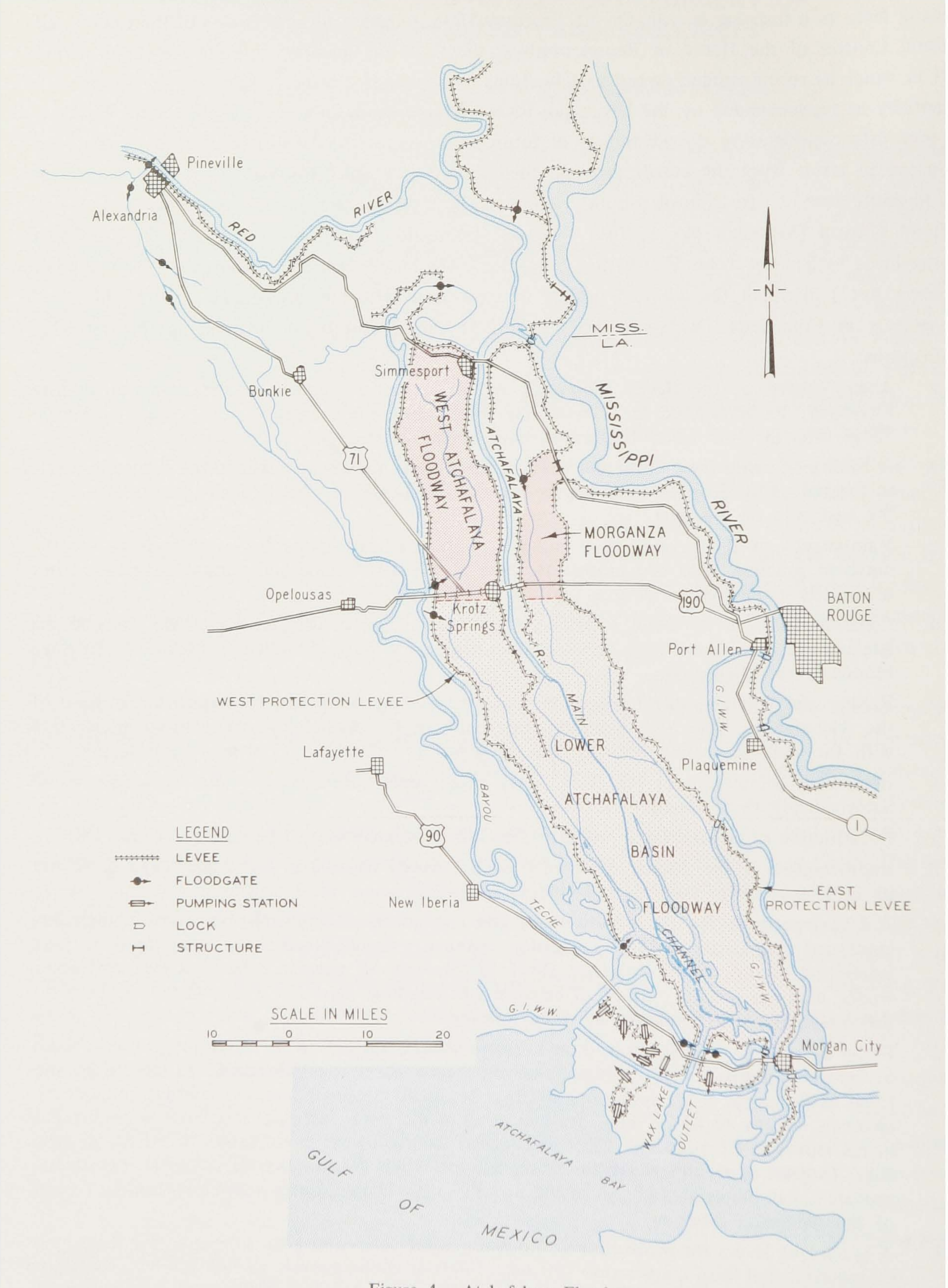

Figure 4. Atchafalaya Floodways

levees, provide flowage and storage rights across lands and properties within the protected area in the event it became necessary to use the area, or a part of it, for an emergency reservoir, and hold and save the United States free from liability for damages on account of the use of the area for reservoir purposes during the emergency.

l. Provision of drainage made necessary by construction of floodway levees, included in the modified project.

m. Construction of railroad and highway crossings over the several floodways.

n. Construction of access roads to inaccessible portions of the levee lines.

With the objective of facilitating acquisition of flowage rights and rights-of-way for levee foundations, the act authorized the Secretary of War to enter into agreement with the States or local agencies for acquisition and transfer to the United States of such rights, with reimbursement to the States or local agencies at prices previously agreed upon, provided that construction of the Eudora Floodway, Morganza Floodway, and appurtenant protection levees could not be commenced until 75 percent of the value of those rights had been acquired, or satisfactory options or assurances had been acquired. The act also provided that easements required for roads and other public utilities owned by States or their political subdivisions should be provided, without cost to the United States, upon the condition that the United States should provide suitable crossings over floodway guideline levees for all improved roads constituting a part of the State highway system. If the remainder of the needed rights and easements could not be obtained by agreement, the act provided for the institution of condemnation proceedings.

It was further stipulated that not more than $20,000,000 should be expended for acquisition of the 75 percent of the value of the flowage rights and rights-of-way for the Eudora Floodway, the Morganza Floodway, the back protection levee extending north from the Eudora Floodway, and the levees extending from the head of the Morganza Floodway to the head of and down the east bank of the Atchafalaya River to the intersection of the Morganza Floodway. The Chief of Engineers was authorized to purchase flowage easements over lands and properties in the floodway west of the Atchafalaya River and lying above the approximate latitude of Krotz Springs, provided that none of such easements in the West Atchafalaya Floodway should be purchased until options covering at least 75 percent of the total value of such easements had been obtained at prices deemed reasonable by the Chief of Engineers and not exceeding, in the aggregate, $2,250,000 for the 75 percent of the easements. The act provided that no flowage easements should be paid for by the United States for properties subject to frequent overflow in the Atchafalaya Basin below the approximate latitude of Krotz Springs. Included also was the stipulation that, if the Secretary of Agriculture should determine to acquire any of the properties within the floodways for natural forests, wildlife refuges, or other purposes of his Department, the Secretary of War, in lieu of acquiring flowage rights, might advance to or reimburse the Secretary of Agriculture sums equal to those that would otherwise be used for the purpose of easements desired by the War Department, and the Secretary of Agriculture was authorized to use those sums for the purpose of acquiring properties in the floodways.

The Overton Act also authorized appropriation of the sum of $15,000,000 as an emergency fund to be allocated by the Secretary of War on the recommendation of the Chief of Engineers in rescue work, or in the repair or maintenance of any flood control work on any tributary of the Mississippi River threatened or destroyed by flood. It made provisions for allotment of the unexpended and unallotted balance of this sum in reimbursing levee districts or others for expenditures incurred for construction, repair, or maintenance of any flood control work on any tributaries or outlets of the Mississippi River that may be threatened, impaired, or destroyed by the flood of 1927 or subsequent flood, or by caving

banks, or that may be threatened or impaired by caving banks of such tributaries, whether or not such caving takes place during a flood stage.

The sum of $272,000,000 was authorized by this act to be appropriated for the accomplishment of the modified adopted project. It is pertinent to note here that the Flood Control Act approved 22 June 1936 (the Omnibus Bill) is highly significant in the history of Federal flood control legislation, although it effected no amendment of the adopted project for the lower Mississippi River. This act declared it to be the policy of Congress that flood control on navigable waters or their tributaries is a proper activity of the Federal Government, in cooperation with States and their political subdivisions, and that the Federal Government should improve or participate in the improvement of navigable waters or their tributaries, including their watersheds, for flood control purposes, if the benefits to whomsoever they may accrue are in excess of the estimated cost, and if the lives and social security of people are otherwise affected. Section 3 of this act laid down conditions of local cooperation for such works, identical to those contained in section 8a of the 15 June 1936 act, which have come to be known as the "a, b, c" requirements, in these terms:

> * * * hereafter no money appropriated under authority of this act shall be expended on the construction of any project until States, political subdivisions thereof, or other responsible local agencies have given assurances satisfactory to the Secretary of War that they will (a) provide without cost to the United States all lands, easements, and rights-of-way necessary for the construction of the project, except as otherwise provided herein; (b) hold and save the United States free from damages due to the construction works; (c) maintain and operate all the works after completion in accordance with regulations prescribed by the Secretary of War * * *.

Section 8 of the Omnibus Bill expressly provided that nothing in the act should be construed as repealing or amending any provision of the 1928 act or amendments of it.

The Flood Control Act approved 28 August 1937 included in section 6 specific authorization for the Chief of Engineers to modify the project for the control of floods on the Yazoo River, authorized by the act of 15 June 1936, to substitute therefor a combined reservoir, floodway, and levee plan, provided that the total cost did not exceed the previous authorization, and subject to conditions of local cooperation requiring local interests to make highway alterations; to meet damages due to such alterations; and to furnish lands and easements for construction of levees and drainage ditches.

By resolution dated 10 February 1937, the Committee on Flood Control of the House of Representatives requested the Chief of Engineers to review previously submitted reports in the light of new reports and data obtained from the 1937 flood in the Ohio and Mississippi Valleys, and to submit revised comprehensive plans for protective works in the Ohio Valley and plans further to insure protection in the Mississippi Valley. The report in response thereto, dated 6 April 1937, was printed as Committee Document No. 1, Committee on Flood Control, House of Representatives, 75th Congress, 1st session. The Chief of Engineers recommended that the act of 15 May 1928, as amended by the act of 15 June 1936, be further amended to authorize:

a. The purchase in fee simple of all lands in the Morganza, Atchafalaya, and Eudora Floodways (including extension of the Eudora), and the construction of each of these floodways as soon as the lands for each had been acquired.

b. In the discretion of the Secretary of War, the turning over of lands purchased in the floodways to the Department of Agriculture or other public agency under restrictions necessary to insure their proper use for floodway purposes.

c. Reimbursement of or advancement to the Department of Agriculture or other Federal agency from flood control appropriation funds applied to the purchase of lands in the floodways, provided they be utilized in such manner as not to interfere with the purpose of the floodways.

d. Protection of lands in the vicinity of Cairo by construction of a levee upstream from Cairo along the Ohio to high ground; diversion of Cache Creek into the Mississippi, affording protection to the towns of Mounds and Mound City, and protection of lands in the vicinity of Cairo by means of a levee; and raising of the Cairo floodwall.

e. Authorization of the appropriation of an additional $52,000,000, to be applied to strengthening of levees, extension of the levee road system, prosecution of the program for increasing the discharge capacity of the main stem of the Mississippi, and protection of the Cache Creek area.

Bills to amend further the 1928 act, as amended by the 1936 act, were subsequently introduced in the Senate and House of Representatives, and hearings pertaining to them were held in March and April 1938 by a subcommittee of the Senate Committee on Commerce and by the House Committee on Flood Control. These hearings developed the fact that, after almost 2 years of effort, less than 30 percent of the requisite options for the Eudora Floodway had been secured, whereas nearly 85 percent had been obtained in the Morganza Floodway. Testimony also brought out that there was no engineering reason why construction of the Morganza Floodway should not precede that of Eudora. However, apprehension was expressed that separation of the two floodways might result in construction of Morganza and elimination of Eudora. Despite improvement in the channel capacity of the middle reaches of the river due to dredging and cutoff construction to the extent that the great 1937 flood was passed without any crevassing of levees, there was general agreement that provision of diversion for the middle section of the river was imperative. The possibility of occurrence of floods greater than those of 1927 and 1937 was admitted but, at the same time, the possibility of synchronization of great floods from all important tributaries was discounted in view of findings by Weather Bureau studies made in cooperation with the Corps of Engineers.

By the act of 28 June 1938, Congress modified the project adopted by the 1928 act, as amended by the 1936 act, in accordance with the recommendations of the Chief of Engineers in his report of 6 April 1937, except with respect to purchase in fee simple of lands and the increased authorization of $52,000,000. In lieu thereof, an increase in authorization of $40,000,000 was provided, to be applied for the purposes set forth in the Chief's report with the exception stated. The act authorized the acquisition of easements in the Morganza Floodway, modification of its design and inflow, and its construction without delay. Similarly, with respect to the Eudora Floodway, it authorized acquisition of flowage easements and floodway construction, with the provision that the intakes should include an automatic masonry weir with its sill at an elevation that would not be overtopped by stages other than those capable of producing a stage of 51 feet or over on the Vicksburg gage. The provision was added that a fuseplug levee loop might be constructed behind the sill to prevent flow into the floodway until the predicted flood exceeds the safe capacity of the main-river leveed channel, with a freeboard of at least 3 feet, but that the fuseplug levee might be artificially breached when, in the opinion of the Chief of Engineers, such breaching is advisable to insure the safety of the main-river controlling levee line.

Discretionary authority was given the Chief of Engineers to extend the guideline levees of the Eudora Floodway south toward Old River, and to construct the Eudora Floodway at such location as he might determine in the vicinity of Eudora. Irrespective of other provisions of law, authority was given to proceed to acquire flowage easements in the northward extension of the Eudora Floodway, provided that, pending completion of the northward extension, all the riverside fuseplug levee extending south from the vicinity of Yancopin to the vicinity of Vaucluse, Arkansas, so as to connect with the existing levee of 1928 grade and section, should be reconstructed to the 1914 grade and 1928 section. The fuseplug levees at the head of the Atchafalaya Basin were to be constructed to 1928 grade and section. If the back

protection levee was constructed prior to construction of the Eudora Floodway, it was to be connected with the main Mississippi River levee and subsequently connected with the floodway when constructed. The act authorized acquisition of flowage easements over all lands not subject to frequent overflow in the Atchafalaya Basin below the latitude of Krotz Springs. It further stipulated that the Morganza Floodway should not be operated until the Wax Lake Outlet had been placed in operative condition. In lieu of the former restriction, the act permitted acquisition of flowage rights, flowage easements, rights-of-way for levee foundations, and titles in fee simple as provided either by voluntary acquisition or by condemnation proceedings.

The act further authorized the retention by the Federal Government of ownership of title to any lands in fee simple or any part thereof instead of turning them over to the ownership of States or local interests as provided by the 1928 act. Such lands could be leased, provided that 25 percent of all moneys received during any fiscal year from such leases should be paid by the Secretary of the Treasury to the State in which such property is situated, to be expended as the State Legislature may prescribe for the benefit of the public schools and public roads of the county or counties in which such property is situated. Section 2 of the act provided that the a, b, c requirements of section 3 of the act of 22 June 1936 would apply to all flood control projects, except as otherwise specifically provided by law, and it excluded them from application to dam and reservoir and channel-improvement or channel-rectification projects authorized by the acts of 15 May 1928, 15 June 1936, 22 June 1936, and 28 June 1938.

A resolution of the Committee on Flood Control of the House of Representatives, adopted 2 August 1939, called upon the Chief of Engineers to review the adopted project, as amended, and to make recommendations for modifications deemed advisable. A second resolution, adopted 12 March 1940, by the Committee on Commerce of the Senate to the same effect stipulated that the report "review the project as one comprehensive whole and in its entirety." The resulting report of the Mississippi River Commission, dated 7 March 1941 and printed in House Document 359, 77th Congress, 1st session, found the portions of the project north of the Arkansas River and south of Red River to be adequate and satisfactory from the engineering standpoint, having the approval and support of the great majority of local interests concerned, and well on their way to completion. It found, further, that the 1928 and 1936 plans for the middle section of the river were adequate from an engineering standpoint, but both were unacceptable for other reasons to local interests on the west bank of the river. The obvious conclusion was that any further modification, to be successful, must be based on considerations other than those of engineering adequacy.

The Mississippi River Commission, in considering possible revisions of the plan in the middle section, noted that at the time of formulating the Boeuf Floodway in 1928, the capacity of the main leveed channel was estimated at about 1,950,000 cubic feet per second (c.f.s.) and the capacity of the floodway at about 1,250,000 c.f.s. In 1941, the capacity of the main-river leveed channel was estimated to be about 2,600,000 c.f.s. The Commission observed that, had this capacity existed in 1928, serious consideration quite probably would have been given to confining the project flood between the main-line levees, because to do so would not have involved such substantial increases in levee heights as were formerly estimated. Likewise, consideration would have been given to a west-side floodway of less capacity than the one recommended and adopted.

The Commission presented five plans, comprised of the then existing project (plan 1) and four alternatives thereto. Plan 2 would eliminate the Eudora Floodway extension, and would retain a narrow, uncleared floodway. Plan 3 would reduce the west-bank floodway by omitting its southern portion, but

would retain the floodway extension plan. Plan 4 would eliminate both the Eudora Floodway and its northern extension and confine floods between levees of equal grade on both banks, with net levee grades set 1 foot above the computed crest flow line of the project flood. Plan 5, termed an interim plan, consisted of readjusting the grades and equalizing existing freeboards of the west-bank levees to a net grade 3 feet above the flow line of a confined 1927 flood, and the east-bank levees to a grade 6 feet above the same flow line. The latter grade was tantamount to 1 foot above project flood confined. The questions of whether a west-bank overland floodway should or should not be built, and, if built, its location and dimensions would be deferred until future results obtained from reservoirs and channel improvements and the records of future floods should make requirements more definitely determinable.

The cost estimates showed that the levee plans (plans 4 and 5) would be substantially lower than any of the other three, hence were desirable from a fiscal standpoint if they could be made acceptable to local interests. Moreover, a levee plan was deemed to be physically feasible, two developments having made it so. One was the rapid advance in the science of soil mechanics, coupled with the wide experience in levee construction gained during the preceding decade, which, as a result, permitted a more assured approach to the problem of constructing embankments. The other was the remarkable lowering of the flood plane of the middle section of the river by means of channel improvement since 1932, bringing required levee heights down to values no greater than those already in existence at many points along the river. The Commission concluded that any of the five plans could be executed if and when local interests on the east and west sides of the river should compose their differences. As those differences were not of an engineering nature, the Commission believed that only Congress could fix the policy to be followed.

The recommendations of the Commission, in which the Chief of Engineers concurred, included the following:

a. The engineering plan for flood control of the Yazoo River was to be as authorized by the 1936 and 1937 Flood Control Acts, except that the levee on the east bank of the Mississippi River could be extended generally along the west bank of the Yazoo River to a connection in the vicinity of Yazoo City with the Yazoo River levee previously authorized.

b. Construction of a levee from the main-line levee on the west bank of the Mississippi River in the vicinity of Shaw, Louisiana, westward and northward to the vicinity of Newlight, Louisiana, for the protection of that part of the Red River backwater known as the Tensas-Cocodrie area.

c. Procurement at the expense of the United States of rights-of-way and flowage easements required for future setbacks of main-line Mississippi River levees.

d. Appropriations made for any part of the project could be expended upon any feature of the project as modified, with the proviso that funds expended thereafter for maintenance should not be considered as reducing remaining balances of authorizations.

At extensive hearings held by the Committee on Flood Control, House of Representatives, in May 1941, the report of the Mississippi River Commission, which had not at that time been submitted to Congress, was incorporated in the record. The levee plan giving equal protection to both banks was acceptable to local interests on the west side of the river, but not to those in Mississippi, principally because (a) it would raise the project flood stage at Vicksburg to 62-1/2 feet on the Engineer gage (2-1/2 feet higher than was originally premised under the then existing project and 5 feet higher than would be experienced under existing flow conditions), and so would inundate an added 247,000 acres of the lower Yazoo Basin; and (b) it would wipe out the levee grade superiority of 3 feet accorded the east bank under the then existing project, thus exposing both sides equally to inundation by a flood

exceeding in volume the project flood upon which the levee grades were based. This plan the east-bank interests considered improper because of the higher and older development of east-bank lands, and because the topography of this part of the Mississippi Valley would force any surplus waters released through east-bank levee breaks to reenter the river at Vicksburg and so, presumably, in any event, to break into the west-bank basins farther downstream. The Mississippi interests strongly favored adoption of plan 5, the so-called interim plan.

By the act of 18 August 1941 (Public Law 228, 77th Congress), Congress modified the 1928 act, as amended, to provide for the construction of plan 4, with the proviso that the levees in the Yazoo Basin on the east bank of the Mississippi River south of the Coahoma-Bolivar County line should have a 3-foot freeboard over the project flood, and all levees should be constructed with adequate section and foundation to conform to increased levee heights. The Boeuf Floodway, the Eudora Floodway and its northward extension, and the back protection levee were abandoned. The act also approved a revision of the authorized plan in the Yazoo River Basin, permitting the Chief of Engineers, in his discretion, to substitute combinations of reservoirs, levees, and channel improvements for the authorized plan, and authorized extension of the project to include protection of the Yazoo backwater to 56-1/2 feet on the Vicksburg Bridge gage, with the Sunflower River dammed by the backwater levee and all drainage pumped. Also authorized was extension of the levee on the east bank of the Mississippi River generally along the west bank of the Yazoo River to a connection with the Yazoo River levee near Yazoo City (see figure 5). The estimated additional cost of the Yazoo Basin works was $11,982,000.

The act gave the Chief of Engineers authority to fix the grade of the extension levees along the Yazoo River, with higher levees, in his discretion, so that their construction would give the maximum practicable protection without jeopardizing the safety and integrity of the main Mississippi River levees. Local interests were required to furnish assurances that they would maintain the levees and not raise the backwater levees above limiting elevations established by the Chief of Engineers. There was also authorized the construction of a levee for protection of the Tensas-Cocodrie area in the Red River backwater area (see figure 6) at an estimated cost of $6,976,000, subject to conditions of local cooperation, which included maintenance by local authorities and a restriction against raising the levee above the limiting elevations established by the Chief of Engineers, with the further proviso that, subject to such conditions, the Chief of Engineers might substitute other levees and appurtenant works as might be found after further investigation to afford protection to a larger area in the Red River backwater at a total cost not to exceed $14,000,000, without jeopardizing the safety and integrity of the main Mississippi River levee, and without preventing or jeopardizing the contemplated diversions through the Atchafalaya River and Basin.

The 1941 act further modified the engineering flood control plan for the St. Francis River to permit substitution for a leveed floodway in the adopted project of a ditch in Cross County, Arkansas, beginning near the outlet end of the existing Oak Donnick to St. Francis Bay Floodway and terminating in St. Francis Bay, subject to the furnishing of the a, b, c assurances of local cooperation. The act also authorized channel improvement in Bayous Rapides, Boeuf, and Cocodrie, Louisiana, as contemplated in the report dated 24 March 1941 of the Special Board of Officers, at an estimated cost of $2,600,000. Section 2 of the act reinstated the provisions of the 1936 act respecting the a, b, c requirements for channel-improvement and channel-rectification projects authorized in that act. Additional provisions in the act stipulated that local authorities would be reimbursed for rights-of-way and flowage easements required for future setbacks of main-line Mississippi River levees; that any appropriations theretofore or thereafter made for the project might be expended on any feature; and that funds thereafter expended

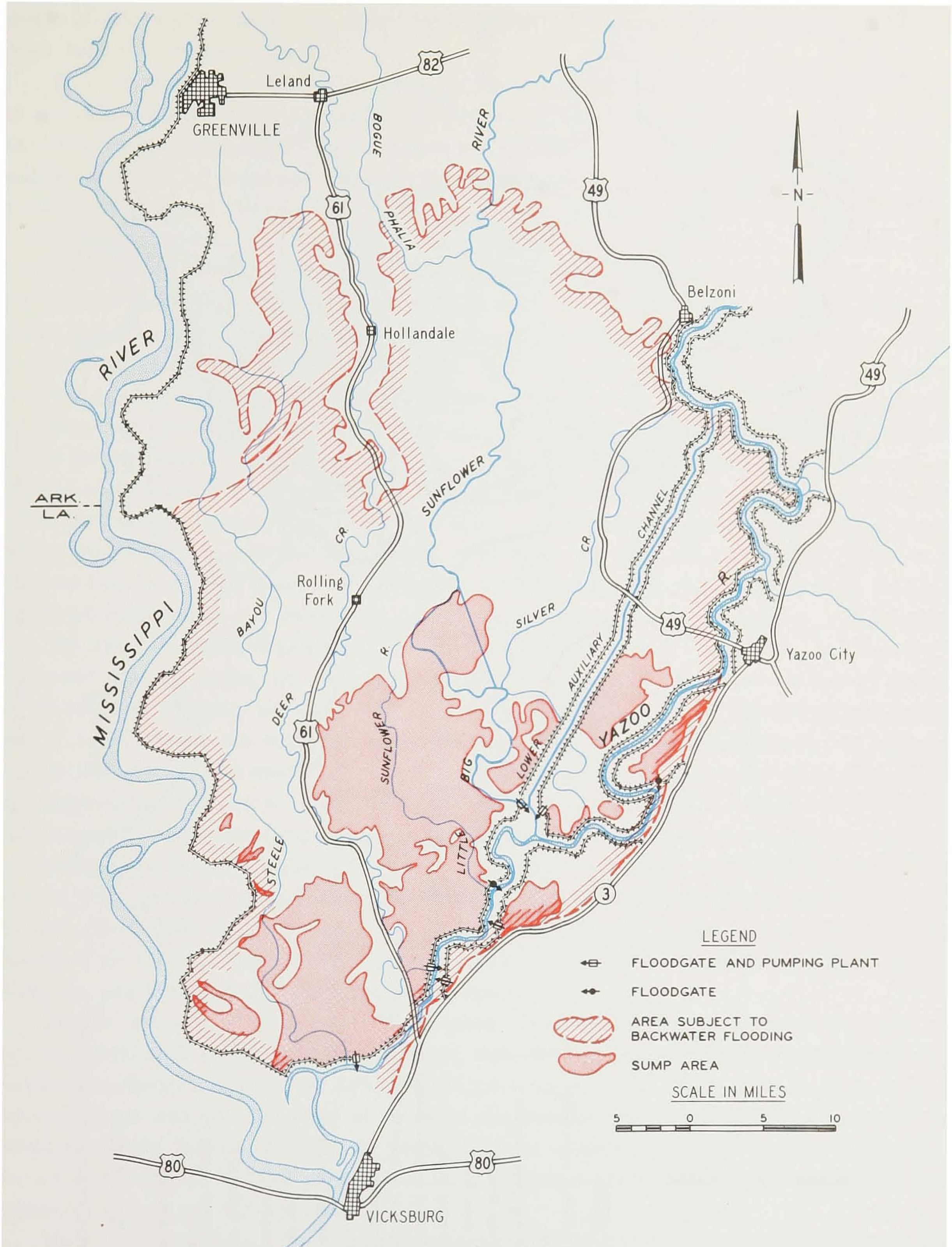

Figure 5. Yazoo Basin - backwater protection plan

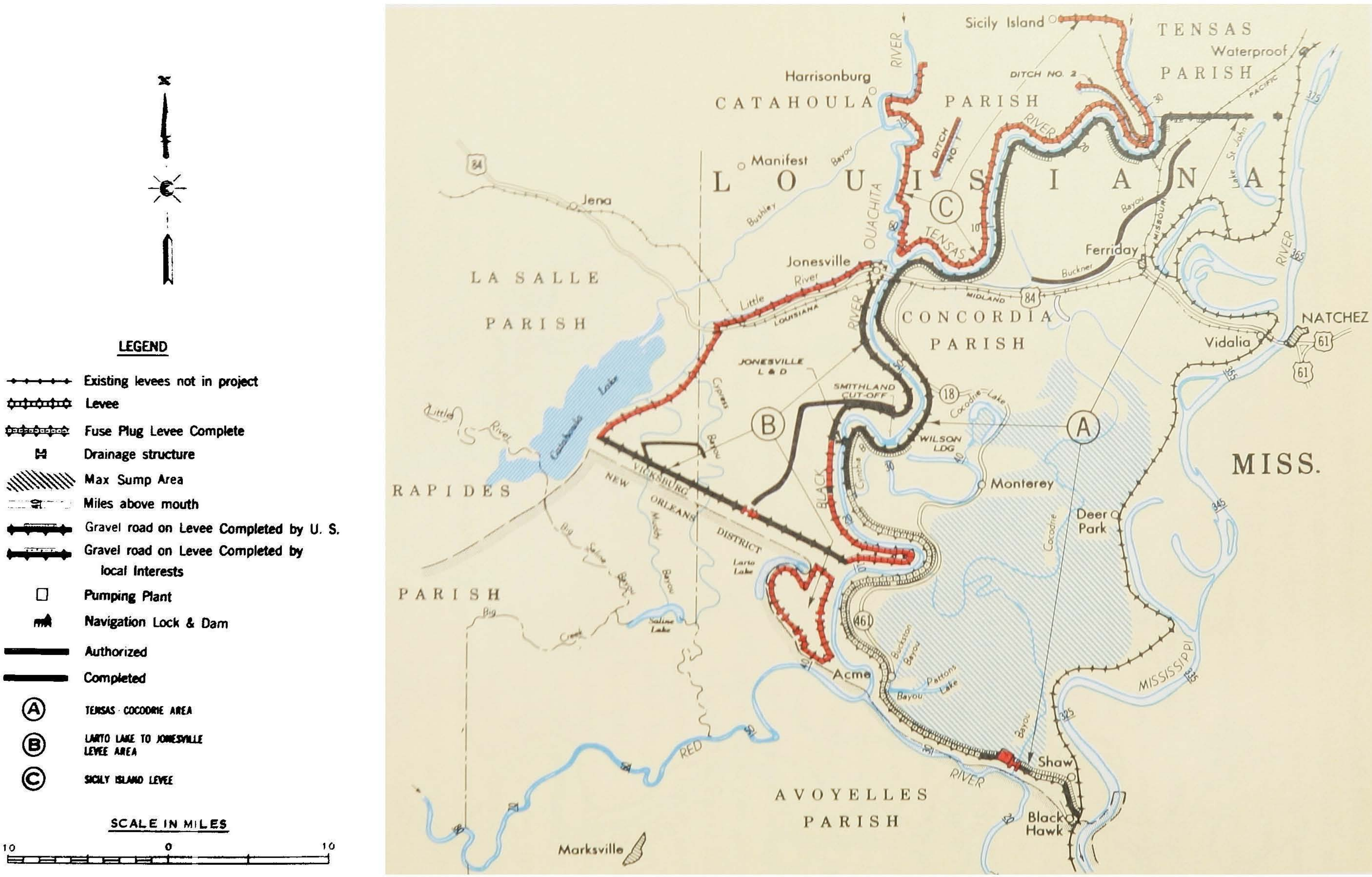

Figure 6. Red River–backwater protection plan

for maintenance would not be considered as reducing remaining balances of authorizations. Finally, the act stipulated that total authorizations theretofore made for the project should not be increased by reason of any provision in the act, except for the additional amounts necessary for the Yazoo and Red River backwater improvements.

By resolution of the House Committee on Flood Control, dated 8 March 1943, and resolution of the Senate Committee on Commerce, dated 9 March 1943, the Chief of Engineers was requested to review the navigation provisions of the project to determine the advisability, in the interest of navigation and flood control, of increasing the depth of the navigable channel from 9 feet to 12 feet between Cairo and Baton Rouge. The report of the Mississippi River Commission, dated 14 February 1944, pointed out that House Document No. 90, 70th Congress, which was enacted into law by the act of 15 May 1928, had visualized the progressive revetment of caving banks to protect levee foundations and to stabilize the river for flood control and navigation, and concluded that the time had arrived in the development of the Alluvial Valley of the Mississippi for undertaking to hold the river's meander within narrow limits as rapidly as funds could be made available. The report expressed the opinion that stabilization of the river was necessary to retain reduction in flood heights obtained by channel rectification, and was advisable for safeguarding the main levees and protecting the investment they represent. The Commission was of the further opinion that such stabilization might materially increase the flood-carrying capacity of the river channel and, with the maintenance dredging already authorized, might provide a minimum depth of 12 feet at low water for navigation. Accordingly, the Commission recommended that the existing project be modified to authorize a navigation channel 12 feet deep and 300 feet wide at low water between Cairo and Baton Rouge, and the execution in the interest of navigation and flood control of a channel improvement and stabilization program at an estimated additional cost of $200,000,000.

The Chief of Engineers concurred, but in transmitting the report to Congress, the Secretary of War noted that the Bureau of the Budget had been consulted and had commented that an appraisal of the economic feasibility and justification of a 12-foot channel on the lower Mississippi could be made only if similar surveys are made for 12-foot channels on the upper Mississippi, the Illinois Waterway, and the Ohio River, which should fully consider, also, the effects of such improvements on other existing and proposed improvements for flood control, hydroelectric power, domestic and industrial water supply and drainage, on pollution control, and on recreation and wildlife resources. The Bureau stated that authorization of those parts of the recommended improvements necessary to provide the 12-foot navigation channel would not be in accord with the program of the President at that time, and that further advice on that aspect would be given by the Bureau of the Budget after "review and consideration of the reports of the Chief of Engineers for 12-foot channels on the Illinois and Mississippi Canal, the Illinois Waterway, and the Ohio and Upper Mississippi Rivers."

By the act of 22 December 1944, Congress modified the project in accordance with the recommendations of the Chief of Engineers and authorized to be appropriated, in addition to sums previously authorized, the sum of $200,000,000 for accomplishment of the purposes set forth in the report. The act also gave the Chief of Engineers discretionary authority to include improvements for protection of the Satartia area, plus its extension, at an estimated additional cost of $1,952,000, in the authorized project for flood protection in the Yazoo backwater area. The total increase in monetary authorization thus was $201,952,000.

The act further stipulated that the term "flood control" used in section 1 of the act of 22 June 1936 should be construed to include channel and major drainage improvements, and, in addition, authorized the Chief of Engineers to construct, maintain, and operate public park and recreational facilities in reservoir

areas under the control of the War Department. Section 3 of the act reaffirmed provisions of the 1938 act with respect to applicability of the a, b, c requirements for projects authorized therein, except that for any channel improvement or channel rectification project, provisions a, b, and c shall apply except as otherwise provided by law. Section 10 of the act declared it to be the intention of Congress, in adopting the projects authorized in that act for the benefit of navigation and flood control, to provide an adequate reservoir of useful and worthy public works for the post-World War II construction program. It further provided that plans, specifications, and preliminary work for any project authorized in that act could be prosecuted during the war with any available flood control funds, so as to be ready for rapid inauguration of a postwar program of construction.

The act of 24 July 1946 made the first post-World War II modifications of the adopted project. It expanded the project to include a number of features previously authorized as separate projects, and authorized and incorporated extensions of them. It also authorized and incorporated new features, and made additional stipulations concerning project features. It reaffirmed applicability of the a, b, c requirements for projects authorized therein, except as otherwise provided by law. The project for flood control on the Boeuf and Tensas Rivers and Bayou Macon, which covered improvement downstream from the Arkansas-Louisiana State line and which was authorized by the act of 22 December 1944 at an estimated cost of $5,013,000, subject to provision of rights-of-way and maintenance at local expense, was incorporated into the Mississippi River and Tributaries Project, and extended upstream above the Arkansas-Louisiana State line. This act also authorized improvement of Bayou Lafourche at an estimated cost of $5,913,000. The upstream extension of the Boeuf and Tensas Rivers and Bayou Macon north of the Louisiana State line was estimated to cost $4,930,000.

Similarly, the project for flood control on the Big Sunflower, Little Sunflower, Hushpuckena, and Quiver Rivers and their tributaries and associated streams, authorized by the act of 22 December 1944 at an estimated cost of $3,752,000, subject to provision of rights-of-way and maintenance at local expense, was incorporated into the Mississippi River and Tributaries Project, and extension of that project, upstream and downstream, including cutoffs as necessary to effectuate the purposes of the plan, was further authorized at an estimated cost of $2,500,000. The authorized headwater project for the Yazoo River and tributaries was extended to include improvements in the area between the Yazoo-Tallahatchie-Coldwater River system and the hills at an estimated cost of $7,500,000, and the drainage of runoff from the McKinney Bayou watershed, or provision of additional pumping capacity, at an estimated cost of $300,000. Section 10 relieved local interests of all requirements for cooperation in the headwater project.

In the area west of the west Atchafalaya Basin protection levee, the Bayou des Glaises diversion channel, authorized by the act of 22 June 1936 subject to the a, b, c requirements but relieved of all local interest obligations by the 1938 act, was incorporated as a feature of the basic 1928 act by the 1946 act. A levee along the north bank of the Arkansas River from North Little Rock to Gillett was also authorized by the act of 22 June 1936 and subject to the a, b, c requirements. The 1946 act modified the project adopted by the 1928 act by incorporating that portion of the north bank levee along and below Plum Bayou, and limited local interest responsibility to maintenance of the levee in accordance with section 3 of the 1928 act.

The local flood protection projects on the White River between Augusta and Clarendon and at DeValls Bluff, at an estimated total cost of $2,847,500, authorized under the act approved 18 August 1941 and subject to the a, b, c requirements, were incorporated in the basic project by the 1946 act. Also incorporated was the Tiptonville and Obion levee, authorized by and constructed

under the act approved 22 June 1936, as well as extension of the levee substantially as recommended by the Chief of Engineers in a report later published in House Document 757, 79th Congress, 2d session, at an estimated cost of $6,000,000; the improvement of St. Johns Bayou, Missouri, as recommended by the Chief of Engineers in a report later published in House Document 138, 80th Congress, 1st session, at an estimated cost of $1,300,000; and improvement of the harbor at Memphis, as recommended by the Chief of Engineers in a report later published in Senate Document 51, 80th Congress, 1st session, at an estimated cost of $17,120,000.

For the Tiptonville and Obion levee, local interests were required to defray the costs of alteration and replacement of existing highway bridges, provide rights-of-way, lands, and easements, and maintain in accordance with section 3 of the 1928 act. In the case of the St. Johns Bayou improvement, local interests were required to maintain and operate after completion. Approval of the Memphis harbor improvement included the stipulation that local interests would furnish all lands, easements, rights-of-way, and spoil disposal areas necessary for initial construction and subsequent maintenance, with the understanding that local interests would install terminal facilities and public utilities required, open to all on equal terms, and would maintain and operate all works other than channel improvements.

The 1946 act modified the main-line levee system of the authorized project to include protection of the potential industrial area immediately north of Vicksburg at an estimated cost of $4,000,000, subject to furnishing of rights-of-way for levees and drainage, and maintenance and operation by local interests, and further modified the authorized Mississippi River and Tributaries Project to provide drainage where drainage is impaired by levees theretofore or thereafter constructed, at an estimated cost of $500,000. The act reduced the requirements of local cooperation for the works authorized in the St. Francis and Yazoo River Basins to stipulate only that local interests maintain levees in accordance with the provisions of section 3 of the act of 3 May 1928, where maintenance was required under existing law. This provision was amended by Public Law 237, 82d Congress, approved 30 October 1951, to include the White River backwater area. The total increase in monetary authorization was $161,675,500, of which $100,000,000 was provided to cover increased construction costs. Finally, the act authorized the Chief of Engineers to include at Federal expense the necessary alterations of railroad bridges and approaches in connection with authorized flood protection projects, and amended the 1944 authorization respecting public park and recreational facilities in reservoir areas to permit the granting of leases to nonprofit organizations at reduced or nominal rentals.

The Flood Control Act of 1948 (title II of Public Law 858, 80th Congress) further modified the organic act by incorporating therein a project at Baton Rouge authorized by the River and Harbor Act of 1946—the barge channel through Devils Swamp—at an estimated cost of $2,000,000. It also authorized channel improvements for flood control and drainage in the West Tennessee tributaries at an estimated cost of $7,700,000 subject to provision of rights-of-way, construction or alteration of certain bridges, and maintenance of the improvements at local cost. It approved similar works in L'Anguille River, Arkansas, subject to provision of lands, easements, rights-of-way, and maintenance at local cost, at an estimated cost of $5,100,000, but limited the monetary authorization to $2,000,000. Thus, the total increase in authorization was $11,700,000. Section 201 of this act reaffirmed applicability of the a, b, c requirements for projects authorized therein, except as otherwise provided by law.

By the Flood Control Act of 1950 (title II of Public Law 516, 81st Congress), Congress further modified and expanded the basic act. An increase of $15,000,000 was made in the authorization for the protection levee in the Tensas-Cocodrie area of the Red River backwater, bringing the total cost figure to $29,000,000. The plan for flood protection and major drainage improvements in the St. Francis

River Basin, Missouri and Arkansas, as outlined in House Document 132, 81st Congress, 1st session, was approved, and a monetary authorization of $20,000,000 was made for its partial accomplishment. The improvements of the Boeuf and Tensas Rivers, Bayous Macon and Lafourche, Big Sunflower, Little Sunflower, Hushpuckena, and Quiver Rivers and their tributaries and associated streams, as authorized by the Flood Control Act of 1946, were relieved of the a, b, c requirements for local cooperation, and in lieu thereof, local interests were required only to maintain works in accordance with the provisions of section 3 of the 1928 act. The plan for flood protection and related purposes in the Cache River Basin, outlined in Senate Document 88, 81st Congress, 1st session, was approved and a partial monetary authorization of $10,000,000 was made for its partial accomplishment subject to conditions that rights-of-way and maintenance be provided at local expense.

The act extended Federal flood control improvements to include Orleans Parish, Louisiana, from which they were excluded by the 1928 act. Also adopted was a project for flood protection at Des Arc, Arkansas, on the White River at an estimated cost of $228,000, as recommended by the Chief of Engineers in House Document 485, 81st Congress, subject to conditions that rights-of-way and maintenance be provided at local expense. The Lake Pontchartrain levee, authorized by the Flood Control Act of 1946, was adopted as a project feature, and its scope was expanded to include levee strengthening and interior drainage, at a total estimated cost of $6,900,000, subject to terms of local cooperation calling for provision of rights-of-way; contribution of 25 percent of the construction cost; holding and saving the United States free from damages due to the improvement; furnishing assurances as to altering bridges; improving existing facilities, including drainage canals and pumping plants as required; preventing unauthorized erection of structures on the embankment or rights-of-way; and maintaining and operating. The additional sum of $5,000,000 was authorized to be appropriated as an emergency fund for the purposes set forth in a similar authorization in the Overton Act of 15 June 1936.

The plan of improvement for the Grand Prairie-Bayou Meto area in Arkansas for flood control, water supply, and drainage was also authorized by the Flood Control Act of 1950, as recommended by the Chief of Engineers in House Document 255, 81st Congress, 1st session, at an estimated cost of $25,183,000, and partial authorization in the sum of $6,000,000 was given. The authorization was subject to operation, maintenance, and provision of rights-of-way at local cost, and reimbursement to the United States for the portion of the costs allocated to local interests for providing and delivering water to the Grand Prairie area. The previously authorized project for flood protection on the Ouachita River at Jonesville, Louisiana, was incorporated in the basic Mississippi River and Tributaries Project. The act approved minor projects for filling Grant's Canal at Lake Providence, Louisiana, and providing emergency bank protection at Amite, Louisiana. In order to provide for increased costs of construction of previously authorized projects, the monetary authorization for the basic project was increased by $200,000,000. The total increase in monetary authorization provided by the 1950 act was $254,439,000. Section 201 of the act reaffirmed application of the a, b, c requirements for projects authorized therein, except as otherwise provided.

Based on reports of the Mississippi River Commission and the Chief of Engineers, contained in House Document 478, 83d Congress, 2d session, the Flood Control Act of 1954 authorized control of Old and Atchafalaya Rivers and a navigation lock (see figure 7). The control plan envisaged two mechanically operated control structures with inflow and outflow channels on the right bank of the Mississippi River, an earth closure dam in Old River, and enlargement and extension of main-line Mississippi River levees with bank stabilization as required, all at an estimated additional cost (exclusive of the navigation lock) of $32,000,000 in addition to the $15,000,000 increase in authorization made by the

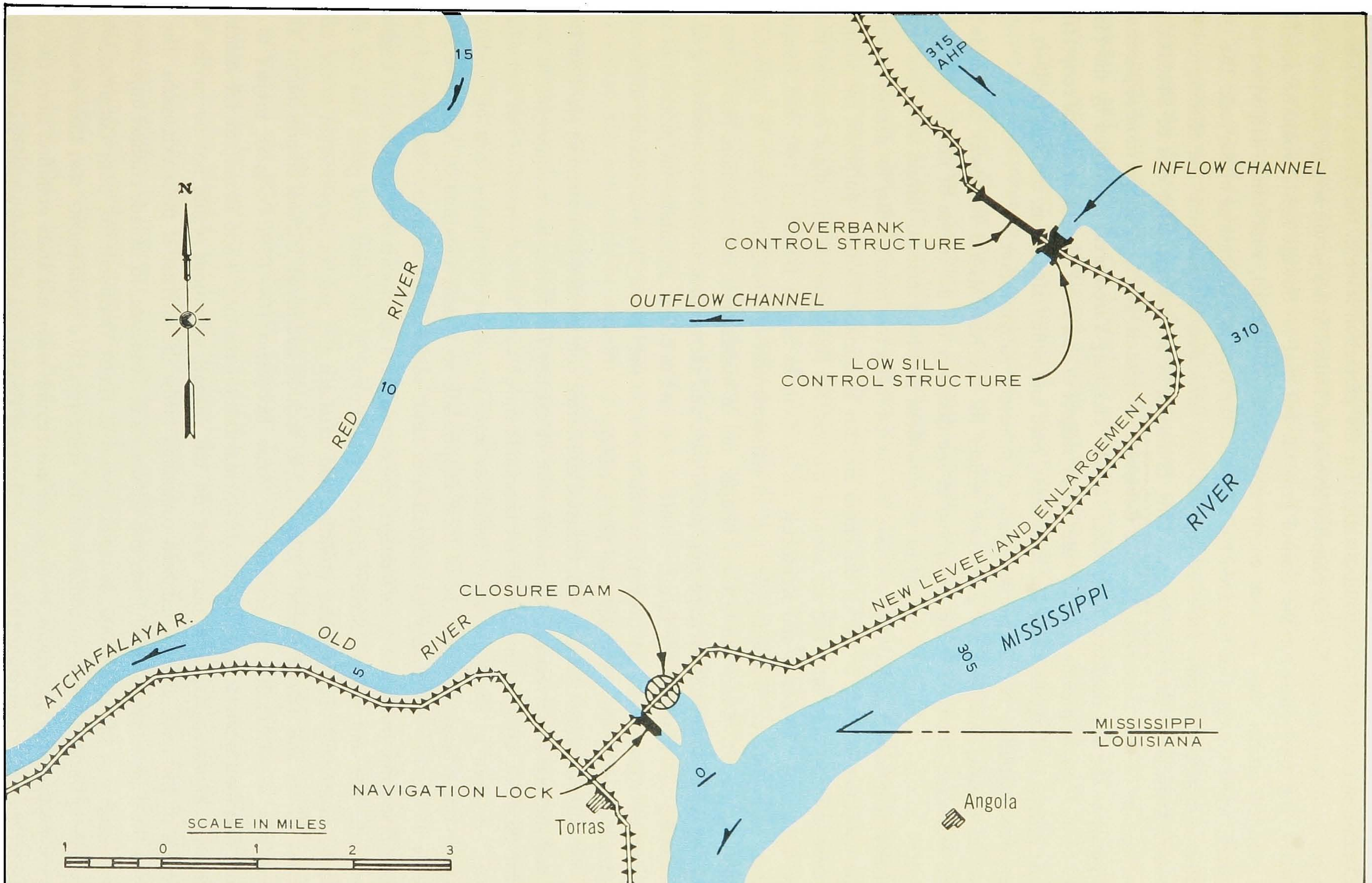

Figure 7. Old River Control - plan

Flood Control Act of 1950 in the authorization for the protection levee in the Tensas-Cocodrie area. The act provided that, except for the main-line levees, the United States would acquire necessary lands, rights-of-way, and spoil areas for the control projects, but that no flowage rights would be acquired.

It provided further that the lock construction could be initiated, with funds authorized to be appropriated, when the Chief of Engineers had approved the type and dimensions of the lock. The 1954 act further authorized the plan for a 12- by 125-foot navigation channel from the Mississippi River via Old and Atchafalaya Rivers to Morgan City, Louisiana, at an estimated first cost of $440,000, as recommended in Senate Document 53, 82d Congress, 1st session. No local cooperation requirements were stipulated. The act modified the project for the Vicksburg-Yazoo area, authorized by the Flood Control Act of 1946, to provide for a substitute plan, subject to additional conditions of local cooperation to include provision of rights-of-way for spoil areas, road and utility alterations, terminal facilities, and necessary public utilities. No change was made in monetary authorization.

The act likewise modified the authorized project for the New Madrid Floodway to provide for a closure levee and floodgate at the lower end of the floodway for the release of interior drainage at an estimated cost of $1,743,000, subject to the conditions that local interests furnish lands, easements, rights-of-way, and flowage rights; hold and save the United States free from liability for damages resulting from the construction work or use of the entire area for authorized floodway purposes; and maintain and operate the improvements. The act adopted the plan for flood control and major drainage in the Reelfoot Lake area, Tennessee and Kentucky, as set forth in Senate Document 160, 83d Congress, 2d session, to include channel enlargement at an estimated cost of $748,100, subject to provision by local interests of rights-of-way and highway bridges, and of maintenance and operation. Finally, the act amended the 1946 authorization respecting public park and recreational facilities in reservoir areas to permit licensing to cut timber for further beneficial uses and to collect and utilize the proceeds of sales in development, conservation, maintenance, and utilization of such lands. The total increase in monetary authorization made by the 1954 act was $34,931,000.

By the Flood Control Act of 1958, Congress authorized construction of a pumping plant for flood control and drainage improvement, and modification of existing floodgates, as recommended in Senate Document 26, 85th Congress, to provide for impoundment of water for the benefit of fish and wildlife in the area enclosed by the White River backwater levee system, at an estimated cost of $2,380,000 for construction, subject to assurances of local cooperation to include provision of rights-of-way and of drainage improvements necessary for utilization of lands adjoining the sump area; holding and saving the United States free from liability for damages; and entering into agreements with the Corps of Engineers and the U. S. Fish and Wildlife Service concerning operation of the plant and gates, and the sump levels to be maintained. The act also modified and extended the plan of improvement in the Boeuf and Tensas Rivers and Bayou Macon, Arkansas, to include additional channel improvements at an additional cost of $1,212,000, as described in House Document 108, 85th Congress, subject to the conditions that local interests agree to operate and maintain the channels and to accomplish the associated local drainage improvements, and that work on the channel extensions would not be started until construction of the main arteries had been completed below the mouths of these extensions. The act authorized flood protection of Wolf River and tributaries in Tennessee, to include channel improvement, at an estimated cost of $1,932,000, as recommended in House Document 76, 85th Congress, subject to assurances by local interests, in addition to the standard a, b, c requirements, that they would make necessary highway bridge alterations; construct an intercepting sewer and abate pollution along the lower 3.2 miles of the river; contribute 19 percent of the gross Federal cost of construction; state their desire

that the flood control improvement be constructed in lieu of the upstream extension of the authorized navigation project, and that such navigation improvement be eliminated from the authorized project; and that they would construct at least 50 percent of the local drainage improvements in the tributary area, as recommended by the Department of Agriculture.

The act expanded the basic project to provide for Federal participation in improvement of the harbor channels at Greenville, Mississippi, and construction of an adjacent port area, in accordance with a report of the Mississippi River Commission (later printed in Senate Document 15, 86th Congress, 1st session) at an estimated Federal cost of $1,799,500 for dredging 12 feet deep plus 3 feet of overdepth, and one-half of the 17 feet of additional depth, provided that the cost for dredging the remaining one-half of the additional 17-foot depth, estimated to cost $383,500, shall be returned to the Federal Government with interest at 3 percent in 40 equal annual installments. In addition to the standard a, b, c requirements, the authorization stipulated that local interests should accomplish, without cost to the United States, the construction of the highway and railroad approach fill, slope treatment, and utility relocations; construct and operate adequate terminal and transfer facilities open to all on equal terms; and establish a public body empowered to regulate the use, growth, and free development of the harbor facilities, and to limit occupancy of the port area to industries whose activities are integrated to water transportation. Maintenance of the harbor and connecting channels was excluded from the requirements for maintenance by local interests. The 1958 act further authorized appropriations of additional sums of $28,200,000 for the Old River Control Project, and $35,674,000 for the improvement of the St. Francis Basin. The total increase in monetary authorization was $71,197,500.

The Flood Control Act of 1960 increased the monetary authorization for the project in the amount of $50,000,000 to provide for the continued prosecution of the channel-improvement feature.

The Flood Control Act of 1962 modified the basic project to provide that monetary authorizations theretofore and thereafter made available to the project or any portion thereof should be combined into a single sum and should be available for application to any portion of the project. It also expanded the project to include construction of improvements in Gin and Muddy Bayous, Yazoo River Basin, at an estimated cost of $150,000, subject to approvals of the Secretary of the Army and the President of the United States, which are reproduced in House Document 358, 89th Congress, 2d session. Local interests are required to maintain and operate the completed project. The project for a barge channel through Devils Swamp, Louisiana, authorized by the River and Harbor Act of 1946 and incorporated into the Mississippi River and Tributaries Project by the Flood Control Act of 1948, was amended by making provision for dikes and other retaining structures at a Federal cost of $299,500, provided that local interests contribute $100,500 toward the cost of the work. The lower auxiliary channel, Yazoo River Basin, was designated as the Will M. Whittington Auxiliary Channel in honor of the late Member of the House of Representatives and former Chairman of the House Public Works Committee. The 1962 act authorized the replacement, with adequate floodway capacity, of two bridges in Chicot County, Arkansas, which had been altered as part of the project for Boeuf and Tensas Rivers and Bayou Macon, authorized by the Flood Control Act of 1944, and which had been destroyed by floods. The estimated cost was $115,000. The 1962 act further amended the 1944 authorization respecting public park and recreational facilities in reservoir areas to permit construction by local interests, particularly of those facilities to be operated and maintained by such interests, and to permit maintenance and operation of such facilities by local interests. The total increase in monetary authorization was $564,500.

Public Law 89-42, approved 18 June 1965, an act authorizing additional appropriations for prosecution of projects in certain comprehensive river basin plans for flood control, navigation, and other

purposes, increased the monetary authorization of the project for the lower Mississippi River in the amount of $53,000,000.

By the Flood Control Act of 1965, Congress amended the organic act generally in accordance with recommendations of the Chief of Engineers in House Documents 308 (printed in six volumes) and 319, 88th Congress, 2d session, and Senate Document 57, 89th Congress, 1st session. The report of the Chief of Engineers, in response to a resolution of the Public Works Committee of the Senate adopted 12 June 1954, calling for an examination and review of the project, as authorized and amended, "as one comprehensive whole and in its entirety," took into consideration the comprehensive review report made by the Mississippi River Commission; further studies made by the Commission subsequent to completion of its report; and the views of State and Federal agencies. The act of 1965 expanded the Mississippi River and Tributaries Project by authorizing new work as follows:

a. Channel improvements, consisting of revetments and batture protection works below Baton Rouge, Louisiana, at an estimated cost of $145,219,000.

b. Levee improvements in the main-stem levee system and modification of the Birds Point-New Madrid Floodway at an estimated cost of $2,165,000. The local cooperation required for the new levee work conforms to that of previously authorized work. Modified flowage easements required in the Birds Point-New Madrid Floodway are to be acquired by the Federal Government as provided by section 4 of the act of 15 May 1928.

c. Improvement of the south-bank Arkansas River levees at an estimated cost of $36,000, the required local cooperation to conform to that of previously authorized work.

d. Improvement of the south-bank Red River levees at an estimated cost of $584,400, with required local cooperation to be the same as that for the south-bank Arkansas River levees.

e. Drainage channels at Mound City, Illinois, at an estimated cost of $48,000, subject to the a, b, c requirements of local cooperation with the additional stipulations that local interests provide interior drainage facilities for Mound City, and provide all street and highway culverts.

f. In the St. Francis Basin, channel improvements, acquisition of lands for mitigation of fish and wildlife losses, and improvements for flood control in the Big Lake Fish and Wildlife Refuge Area at an estimated Federal cost of $8,362,500; and improvements in the Big Lake area for fish and wildlife enhancement at an estimated Federal cost of $874,200 (about 6 percent of the total cost is to be borne by non-Federal interests), and additional improvements for flood control, drainage, and other water uses within Drainage District No. 7 of Poinsett County, Arkansas, at an estimated total cost of $1,372,000. The authorization called for the local cooperation requirements for improvements in the St. Francis Basin, set forth in the report of the Chief of Engineers, with particular reference to Federal and non-Federal cost sharing, to be reviewed by the Secretary of the Army and the results to be reported to Congress by 27 October 1966.

g. On the lower White River, improvement of the existing local protection levee and associated drainage works at Clarendon, Arkansas, and channel improvements in the Big Creek Basin, at an estimated total cost of $7,950,000, subject to the a, b, c requirements and to the stipulation that local interests make all necessary improvements to highway bridges for the Big Creek Project.

h. In the Boeuf and Tensas Rivers and Bayou Macon tributary basin, channel improvements in Mill and Vidal Bayous at an estimated cost of $350,000, provided that local interests maintain the works after completion.

i. Construction of a pumping plant in the Red River backwater area at an estimated cost of $7,000,000, including lands and developments for the mitigation of fish and wildlife losses, the plant to be maintained and operated by the Corps of Engineers, provided local interests furnish rights-of-way and hold and save the United States free from damages due to the construction works.

j. Channel improvements in Obion Creek, West Kentucky tributaries, at an estimated cost of $1,906,000, subject to the a, b, c requirements and that, in addition, local interests make all necessary alterations to highway bridges.

k. In the Yazoo headwater area, channel improvements in Alligator and Catfish Bayous, Bear Creek, and Whiteoak Bayou, and acquisition of lands in the Hillside Floodway, with minor developments for fish and wildlife mitigation, at an estimated cost of $1,317,000. Also authorized was installation of five water-control structures in the Will M. Whittington Auxiliary Channel (Lower Auxiliary Channel) for fish and wildlife enhancement at an estimated Federal cost of $47,500, which represents an equal division of construction costs between the United States and non-Federal entities, and further subject to the a, b, c requirements of local cooperation.

l. In the Yazoo backwater area, construction of water-control structures in McCann Bayou for fish and wildlife enhancement at an estimated Federal cost of $44,000, with the cost division and local cooperation requirements to be the same as those for the Will M. Whittington Auxiliary Channel Structures.

m. In the Big Sunflower Basin, water-control structures for fish and wildlife enhancement at an estimated Federal cost of $137,000, with the cost division and local cooperation requirements to be the same as those for the Will M. Whittington Auxiliary Channel Structures.

n. In the lower Mississippi River Delta region, four salinity-control structures for fish and wildlife enhancement at an estimated Federal cost of $5,068,500, with the cost division and local cooperation requirements to be the same as those for the Will M. Whittington Auxiliary Channel Structures.

The Flood Control Act of 1965 increased the monetary authorization for the Mississippi River and Tributaries Project in the amount of $182,481,000, bringing the total project monetary authorization to $1,684,922,600. The figure of $182,481,000 represented the estimated current cost of new work authorized. The cost of changes proposed in House Document 308 and additional changes in previously authorized work to reflect 1965 physical conditions and price levels was estimated at $646,966,300, bringing the estimated total cost of the project to $2,323,678,000 as of 1965.

Section 201 of the 1965 act authorized the Secretary of the Army, through the Chief of Engineers, to construct, operate, and maintain any water resource development if the estimated Federal first cost is less than $10,000,000, stipulating that no appropriation shall be made for any such project if it has not been approved by resolutions adopted by the Public Works Committees of Congress. A project so authorized to be constructed would be subject to the same requirement of local cooperation as it would be if its estimated Federal first cost were $10,000,000 or more. It was further stipulated that section 3 of the act of 22 June 1936 (the Omnibus Bill) as amended by section 2 of the act of 28 June 1938 shall apply to works authorized under this title except that for any channel improvement or channel rectification project, the a, b, c provisions of the 1936 act shall apply.

The 1965 Flood Control Act included the stipulation that no appropriations made pursuant to the Mississippi River and Tributaries Project authorization therein should be available for any project other than those set forth in House Documents 308 and 319. This provision was amended by the Flood Control Act of 1966 to state that the monetary authorization of the 1965 act should be combined with the overall monetary authorization theretofore made available for prosecution of the entire project and should be available for application to any portion of it.

The 1966 act further modified the adopted project to authorize, in the Teche-Vermilion Basins, Louisiana, improvements for water supply and other purposes at an estimated cost of $5,100,000, subject to the standard a, b, c assurances of local cooperation, with the additional provision that local interests, prior to construction, agree to expand the pumping plant when and as necessary to bring the total

capacity to 1,300 c.f.s. The act also authorized an item of bank revetment for the protection of existing industrial facilities along the river below Baton Rouge, Louisiana, where, in the discretion of the Chief of Engineers, such bank protection is justified. The project for flood control and drainage in the West Tennessee tributaries, authorized by the 1948 act, was modified to provide for the relocation, at Federal expense, of all gas transmission lines to be relocated by the project, such lines having been constructed subsequent to the 1948 authorization.

The act of 1879, which established the Mississippi River Commission, provided for three members of the Commission to be appointed from civil life, but placed no limitation on their terms in office. In practice, the civilian members had served at the pleasure of the President of the United States. The 1966 act amended the 1879 act to provide that each Commissioner appointed from civil life after enactment of the act should be appointed for a term of 9 years. No prohibition regarding reappointment was stated.

The improvements authorized by the 1965 Flood Control Act in the St. Francis Basin, Arkansas and Missouri, were subject to cost-sharing requirements that local interests provide lands, easements, and rights-of-way; hold and save the United States free from damages; maintain and operate the works after completion; and make all necessary relocations to highway bridges. The local cooperation for the previously authorized project was limited to maintenance of project levees. The 1968 act further modified the project to extend to the improvements authorized in 1965 the same local cooperation requirements of the previously authorized project.

The 1968 act modified the Boeuf and Tensas Rivers and Bayou Macon Project to authorize improvements as recommended in House Document 168, 90th Congress, 1st session, to divert flows that would otherwise enter Lake Chicot, Arkansas, at an estimated cost of $15,240,000. Prior to initiation of construction of the project, local interests are to agree that no fees shall be charged for admission to Lake Chicot and to public recreation areas adjoining Lake Chicot, and that user fees at such lake and areas shall be devoted to recreation purposes. Local interests were required to administer, operate, and maintain the recreation facilities, and insure that they are open to all on equal terms; provide all lands required for specific recreation facilities and make additional contributions necessary to bring the local contribution to not less than 50 percent of project cost charged to recreation, with the provision that local interests may pay this cost, except for lands, over a period of 50 years; perform minor maintenance; and operate the gates on control structures in Connerly and Ditch Bayous.

Improvements in the Belle Fountain ditch and tributaries, Missouri, and Drainage District No. 17, Arkansas, including enlargement of 66 miles of existing channels in the Belle Fountain ditch and tributary area, and the cleanout and enlargement of 35 miles of existing channel and installation of a 700-c.f.s. pumping station in Drainage District No. 17, at an estimated cost of $4,638,000, were also included in the 1968 act. The local cooperation requirement was limited to maintenance of levees.

The project of 1928, as amended, was further modified by the 1968 act to provide pumping plants and other drainage facilities at Cairo, Illinois, and vicinity to the extent found economically justified by the Chief of Engineers, subject to the a, b, c assurances of local cooperation.

Finally, section 210 of the 1968 act stipulated that no entrance or admission fees shall be collected after 31 March 1970 by the United States at public reservoir areas.

In December 1970, the basic Mississippi River and Tributaries Project was further expanded in consequence of resolutions by the Public Works Committees of Congress pursuant to section 201 of the Flood Control Act of 1965, which authorized the Secretary of the Army, through the Chief of Engineers, to construct, operate, and maintain any water resource development if the estimated Federal

first cost is less than $10,000,000. The additions to the basic project made under this authority are as follows:

a. In the Steele Bayou Basin, modifications to provide for routing flows from about 30 square miles north of the city of Greenville, Mississippi, around the city by construction of a dam, channel enlargement, and construction of weirs, at an estimated Federal cost of $3,970,000. Local interests are to construct associated lateral drainage and maintain the project after completion.

b. In Mud Lake, Tennessee, southwest of Ridgely in Lake County, construction of a new inlet channel and a 150-c.f.s. pumping station to discharge into the Mississippi River, at an estimated Federal cost of $456,000. The required local cooperation includes the standard a, b, c assurances and provision of all necessary alterations and replacements of existing utilities, including power lines, bridges, and highways.

c. In Reelfoot Lake—Lake No. 9, Tennessee and Kentucky, located in the Reelfoot Lake Basin in Dyer, Lake, and Obion Counties, Tennessee, and in Fulton County, Kentucky, a modification of the Reelfoot Lake area project for flood control and major drainage adopted by the Flood Control Act of 1954, comprising channel improvement, new channels, and a 500-c.f.s. pumping station with gravity outlet structure, at an estimated Federal cost of $1,468,000. The required local cooperation is the same as that for the Mud Lake Project.

By the Flood Control Act of 1970 approved on 31 December 1970, Congress also modified and expanded the basic project to include the project for flood protection within the areas of eastern Rapides and south-central Avoyelles Parishes, Louisiana, that are drained by the Bayou des Glaises diversion channel, and Lake Long, and their tributaries, substantially in accordance with the recommendations of the Chief of Engineers in Senate Document No. 91-113, at an estimated cost of $15,333,000. No local cooperation was stipulated for the part of the project below mile 41.6, that part of the outlet channel downstream of the junction of the new land cut and the Bayou des Glaises diversion channel, necessary to carry drainage intercepted by the construction of the Atchafalaya Floodway levee. For the portion of the project above mile 41.6, the local cooperation requirements include the a, b, c assurances prescribed by section 3 of the Flood Control Act of 22 June 1936, and, in addition, the provisions without cost to the United States of modifications to roads, highways, bridges, and utilities necessary for construction of the project, and the prevention of encroachment on improved channels.

The 1970 act lengthened the reach of the Mississippi River within which bank revetment could be placed for the protection of existing industrial facilities. By the 1966 act, placement for this purpose was limited to the river below Baton Rouge, Louisiana. Section 207 of the 1970 act changed the upper limit from Baton Rouge to Cairo, Illinois.

Section 210 of the 1970 act modified the project for Obion Creek, West Kentucky tributaries, authorized by the Flood Control Act of 1965, to provide for relocation at Federal expense of all transmission lines (both gas and electric) required to be relocated by this project, or reimbursement or credit to local interests for such relocations made by them. The 1970 act amended the amendment by the 1962 act of the 1944 authorization respecting public park and recreational facilities in reservoir areas. Precedent legislation had given discretionary authority to the Secretary of the Army to determine the water areas of projects to be open to public use generally, without charge when such use shall be determined by the Secretary of the Army not to be contrary to public interest, under such rules and regulations as the Secretary of the Army may deem necessary. The 1970 act added that these regulations might include prohibition of dumping and unauthorized disposal of refuse, garbage, rubbish, trash, debris, or litter of any kind at such water resource projects, either into the project waters or

onto any land Federally owned and administered by the Corps of Engineers, and might provide for penalties for violations.

The 1970 act made three additional provisions respecting water resource projects. Section 209 set forth the intent of Congress that the objectives of enhancing regional economic development, the quality of the total environment, including its protection and improvement, the well-being of the people of the United States, and the national economic development are those to be included in Federally financed water resource projects and in the evaluation of benefits and cost attributable thereto, giving due consideration to the most feasible alternative means of accomplishing these objectives. Section 216 authorized the Secretary of the Army acting through the Chief of Engineers to review the operation of completed projects constructed by the Corps of Engineers in the interest of navigation, flood control, water supply, and related purposes, when such review is found advisable due to significantly changed physical or economic conditions, and to report thereon to Congress with recommendation on the advisability of modifying the structures or their operation, and for improving the environment in the overall public interest. Section 122 provided that the Secretary of the Army through the Chief of Engineers not later than 1 July 1972 shall submit to Congress a report and not later than 90 days after submission shall promulgate guidelines designed to assure that possible adverse economic, social, and environment effects relating to any proposed project have been fully considered in developing such programs and that the final decisions are made in the best overall public interest, taking into consideration the need for flood control, navigation, and associated purposes, and the cost of eliminating or minimizing such adverse effects. Air, noise, and water pollution are to be considered as are destruction or disruption of manmade and natural resources, adverse employment, injurious displacement of people, and disruption of desirable community and regional growth.

The River Basin Monetary Authorization Act of 1971, approved 23 December 1971, authorized appropriation of $97,000,000 in addition to previous authorizations for prosecution of the comprehensive plan of development for the Mississippi River and Tributaries Project. Section 7 thereof further modified the 1928 act to provide that the local cooperation to be furnished thereafter in connection with the Obion River Diversion aspect of the Tiptonville to Obion River, Tennessee, authorized by the act approved 22 June 1936 and amended by the act approved 24 July 1946, shall consist of the requirement that local interests agree to maintain the completed works in accordance with the provisions of section 3 of the 1928 act, and to hold and save the United States free from damage due to the construction works.

Development of Water and Related Land Resources Policy

In passing the 1928 act, Congress accepted a high degree of responsibility for control of the lower Mississippi River, but a national flood control policy was not adopted until passage of the 22 June 1936 act. It has been suggested that the Great Depression of the thirties established the mood which led to the acceptance of this act by creating an urgent need for work relief projects, and by placing the States and cities in such financial condition that they would not undertake such projects by themselves. However, important developments, both within the Federal sphere and outside it, had helped to lay the groundwork for the act.

Following the 1936 act, and as a result of the experience acquired in executing and administering the program it established, new concepts evolved and, with them, new problems came into being. In consequence, Congress has progressively amended and supplemented the 1936 act to reflect a broader view of flood control. Although section 8 of the 22 June 1936 act provided that the act was not to be construed to repeal or amend any provision of the act of 1928, as amended, subsequent amendments of the 1928 act have incorporated project features originally authorized by the act of 1936, and have authorized other features subject to conditions of local cooperation similar to those of the 1936 act.

Whereas in 1936, Congress tended to think in terms of single-purpose flood control projects, the 1944 act declared it to be the policy of Congress to consider projects on a basis of comprehensive and coordinated development, a principle espoused by President Theodore Roosevelt in 1907 in establishing the Inland Waterways Commission "to prepare and report a comprehensive plan for the improvement and control of the river systems of the United States."

By Public Law 89-80 approved 22 July 1965, Congress established the Water Resources Council, comprised of the Secretaries of the Interior, Agriculture, Army, and Health, Education and Welfare, and the Chairman of the Federal Power Commission. The purposes of the Council are to maintain a continuing study and prepare an assessment biennially, or at less frequent intervals if the Council so determines, of the adequacy of supplies of water necessary to meet water requirements in each water resource region of the United States, and the national interest therein, and to maintain a continuing study of the relation of regional or river basin plans and programs to the requirement of large regions of the Nation and of the adequacy of administrative and statutory means for coordination of the water and related land resource policies and programs of the several Federal agencies. The Council is to appraise the adequacy of existing and proposed policies and programs to meet such requirements and it is to make recommendations to the President with respect to Federal policies and programs. Other duties and responsibilities are to establish principles, standards, and procedures for preparation of regional or river basin plans and Federal projects, and to review river basin commission plans.

The National Water Commission was established by an act approved 22 September 1968 to provide for a comprehensive review of national water resources problems and programs. The Commission, consisting of seven members appointed by the President, has the responsibility to review present and anticipated national water resource problems, consider economic and social consequences of water resource development, and advise on such specific water resource matters as may be referred to it by the President and the Water Resources Council. The Commission is to submit such interim and final reports as it deems appropriate, and it is to terminate not later than 5 years from the effective date of the act.

The National Environmental Policy Act of 1969, approved 1 January 1970, declared a national policy intended to encourage productive and enjoyable harmony between man and his environment, to promote efforts which will prevent or eliminate damage to the environment and biosphere and stimulate the health and welfare of man, to enrich the understanding of the ecological systems and natural resources important to the Nation, and to establish a Council on Environmental Quality. The legislation requires that interpretation and administration of policies, regulations, and public laws be in accordance with the policies set forth in the act, and that planning by all agencies of the Federal Government give full consideration to all aspects of environmental effects. It required that there be included in every recommendation or report on proposals for legislation and other major Federal action a detailed statement covering the environmental impact of the proposed action, any adverse environmental effects which cannot be avoided should the proposal be implemented, alternatives to the proposed action, the relationship between local short-term uses of man's environment and maintenance and enhancement of long-term productivity, and any irreversible and irretrievable commitment of resources which would be involved in the proposed action if implemented.

Thus, changing concepts have brought about progressively broader programs under which major outlets are provided to facilitate land drainage; storage of water for irrigation, navigation, municipal, industrial, and pollution-abatement use is provided; recreational facilities are provided; measures for the mitigation and enhancement of fish and wildlife are instituted; and plans for the comprehensive development, use, and conservation of water and related land resources are made and carried out.

CHAPTER III. PROJECT INVESTIGATIONS AND RESEARCH

Procurement and Utilization of Basic Data

It is axiomatic that, in the making of water resources engineering studies, the availability of adequate physical data is essential. Such data are required not only in appraising problems and making designs, but also in evaluating the consequences of completed works. This need has been recognized ever since Humphreys and Abbot started their studies in the 1850's, and accordingly, the collection of basic data has kept pace with the provision of study funds. As new techniques have been devised and facilities for their employment have been developed, the requirements for nature and scope of data have been modified.

The report of the Chief of Engineers, dated 1 December 1927, contained in House Document No. 90, 70th Congress, which was the basis for the act of 15 May 1928, recognized the need for better maps. It noted that, although congressional authority existed for completion of a general utility topographic map of the country subject to availability of funds, contoured maps of the Alluvial Valley with adequate horizontal and vertical controls had not been made by the Federal Government or by the States concerned. To meet this need, a standard topographic survey of the entire Alluvial Valley was included in the adopted flood control plan. Section 5 of the 1928 act provided for utilizing the services and assistance of mapping agencies of the Federal Government in the preparation of maps required in furtherance of the project, the costs to be allotted from appropriations made under the act. Under that authority, the mapping of areas in the vicinities of Cairo and Lake Pontchartrain and a portion of the Yazoo Basin was undertaken by the U. S. Geological Survey. The remaining Alluvial Valley mapping was assigned to the District Engineer offices at Memphis, Vicksburg, and New Orleans. First-order and second-order controls were generally accomplished by the U. S. Coast and Geodetic Survey, and third-order control and map compilation were the responsibilities of the Corps of Engineers. The maps are published at a scale of 1:62,500 in 15-minute quadrangles, and form a part of the standard topographic map of the United States at this scale.

Prior to 1935, quadrangles were compiled from a series of radial plots of aerial photographs based upon a polyconic projection of the ground control. Topography was sketched on scale prints of the aerial photographs and later transferred to drawings by pantograph. Essentially all of the quadrangles that were the responsibility of the Mississippi River Commission were completed by 1939. Lithography of the first editions was performed by the Engineer Reproduction Plant (later the Army Map Service). Subsequently, printing of the quadrangles was assigned to the U. S. Army Engineer Waterways Experiment Station.

In 1939, a revision of all Mississippi River Commission quadrangles was started. Survey data for the revisions were obtained from currently prosecuted land and hydrographic surveys, additional details being furnished by State highway departments and utility companies. World War II caused a suspension of the revision until 1945, when new equipment, developed in connection with the war effort and made available for civil works, greatly increased the speed of completing the revision. Since 1953, much of the remapping has been done with the Kelsh Stereoplotter, which has been of great value in the effort to bring all Mississippi River Commission quadrangles to national map accuracy standards.

In conformity with the authorization given by the 1928 act, the facilities of the U. S. Geological Survey have been used to the fullest practicable extent. The Geological Survey is now, in accordance with an agreed procedure, mapping 7-1/2-minute quadrangles, scale 1:24,000, at a rate of about 48 per

year within the Mississippi River Commission (MRC) mapping area and at a rate of about 32 sheets per year, as needed by the MRC, within the Lower Mississippi Valley Division (LMVD), but outside the MRC area. It is anticipated that the requirements within the LMVD, but outside the MRC area, will reach forty to fifty-six 7-1/2-minute quadrangles per year. The Army Engineer Districts are converting these quadrangles to 15-minute quadrangles, scale 1:62,500, using Corps of Engineers symbols and data.

In addition to the mapping work, hydrographic surveys of the Mississippi River from Cairo, Illinois, to the Gulf of Mexico, including topographic features from levee to levee (or to high ground), were made in 1937-38, 1948-49, and 1961-63. Low water reference planes were revised, as necessary, to reflect changes brought about by the channel-improvement program. These surveys have been published in three folios at a scale of 1:20,000 from Cairo to Head of Passes, and at a scale of 1:10,000 for South and Southwest Passes. In addition, general hydrographic surveys, scale 1:10,000, are made of particular reaches when needed for engineering study and general construction planning purposes, and detailed hydrographic surveys, scale 1:1,000, are made for revetment, dike, and dredging-construction purposes.

Perhaps the most important single advance in the project for mapping the Alluvial Valley has been the development of aerial mapping. Although employed from the beginning of the mapping program, aerial photography was greatly benefited following World War II, when the ready availability of war surplus equipment made possible the development of improved photogrammetric techniques. From 1949 to 1953, the vertical sketchmaster and reflecting projector were used to develop topographic features direct from the photographs. A further improvement was introduced with the Kelsh Stereoplotter, which, as previously noted, was put into use in 1953. This instrument, together with precision aerial cameras having distortion-free lenses, has been of much value in making reconnaissance surveys for many of the engineering projects under direction of the Mississippi River Commission, enabling the production of accurate topographic maps ranging in scale from 1:720 to 1:20,000.

The mapping program has benefited through improvements made in surveying instruments and techniques, including sounding equipment and methods and electronic computation. Mechanical sounding methods were supplanted by sonic equipment in 1938. A wire distance machine was developed in 1942 by the Memphis District for measuring distances over water. Recently, an electronic distance measuring device was put to use in the Vicksburg District to locate sounding points and to extend horizontal control. The most important improvement in sounding methods has been conversion from the radial-arc method to the range-sounding method. The radial-arc procedure (see figure 8) consisted of swinging a sounding boat, attached by piano wire to a pivot point on the bank, on evenly spaced concentric arcs over the area to be surveyed. Upon availability of the new distance measuring devices, it became possible to sound along the range lines, a procedure that doubled the production of survey parties engaged in this work. The radial-arc method continues to be used in some instances where additional underwater detail is desired, as for a revetment failure. Electronic computation procedures have been applied to traverse computation, comparison of cross sections on revetment record and annual resurveys, interconversion of position coordinates, bench mark descriptions, and average low water plane listings; and to tabulation of gage readings, listing discharge observations, and computing daily discharges and reservoir contents. An additional benefit to the overall mapping program that should not be overlooked is the increased emphasis on safety as well as numerous safety provisions that have been added since 1931.

In addition to publication of the individual quadrangles and the folios of hydrographic surveys, as previously described, the Commission publishes, annually, a folio of flood control and navigation maps of the Mississippi River from Cairo to the Gulf of Mexico, scale 1:62,500, which now includes navigation

Figure 8. Radial-arc survey procedures with sounding boat, distance wire, and plane table

charts of the middle Mississippi below Hannibal, Missouri, and also the Mississippi River-Gulf Outlet channel. There have likewise been published similar folios of maps, scale 1:62,500, of the principal tributaries, including the Ouachita-Black; Arkansas; White; Red; St. Francis; Big Sunflower; and the Yazoo-Tallahatchie-Coldwater Rivers. The Commission has also published, from 1959 to 1961, maps of the Alluvial Valley of the lower Mississippi River and tributaries in 28 sheets, at a scale of 1:250,000, showing completed flood control, navigation, and drainage projects.

Closely allied to the Commission's activities in surveying and mapping are its activities in making hydrometric measurements. These include daily observations of stream gages, recording of stages, and the computation of daily discharges based on frequent streamflow measurements. Interest in stream-gaging operations has grown since 1931, partly because of the increase in the number of projects on the tributaries, and due, also, to increased attention being given to water resource matters. The program for the lower Mississippi Valley has, since 1939, been a cooperative one involving, also, the National Weather Service of the National Oceanic and Atmospheric Administration, Department of Commerce, and the Geological Survey of the Department of Interior. In some instances, the Tennessee Valley Authority and other public, as well as private, interests have also cooperated.

Most of the regular gages are now of the self-recording type, and a few are telemark gages.

Measurements of discharge are made regularly at 56 stations, the daily flows being derived by electronic computations. Frequent measurements are made at other points, as required for navigation and flood control purposes. Certain stations in which there is a mutual interest are operated by the Geological Survey or by the Corps, and, in some instances, by both. The National Weather Service also makes stage observations at certain stations, and keeps records of precipitation.

Prior to 1943, the daily stages, results of discharge observations, and computed daily discharges at principal stations on the Mississippi River, and at outlets and tributaries, were published annually in separate pamphlets. Currently, these data are combined in a single publication by each District, which includes a tabulation of highest and lowest stages from previous records and for the current year, and tabulations of the monthly and yearly mean stages of the Mississippi for the current year; the maximum, minimum, and mean discharges of the Mississippi and its outlets and tributaries from previous records and for the current year; the maximum discharges of Bonnet Carré Floodway; and the maximum and minimum contents of reservoirs in the lower Mississippi Valley.

Since 1931, numerous improvements have been made in discharge and gage equipment, and also in the methods of converting observed values into usable data. Practically all computations are now made by the electronic digital computer. As previously noted, the sonic depth finder has replaced the sounding line. The winch for the current meter is now electric powered. Except when direction of flow is required to be noted, the Price current meter is still used for stream-velocity observation (see figure 9).

In order to obtain more complete hydrographic data, the Corps has, since 1937, transferred each year to the Weather Bureau (now the National Weather Service) sums from its appropriated funds, to

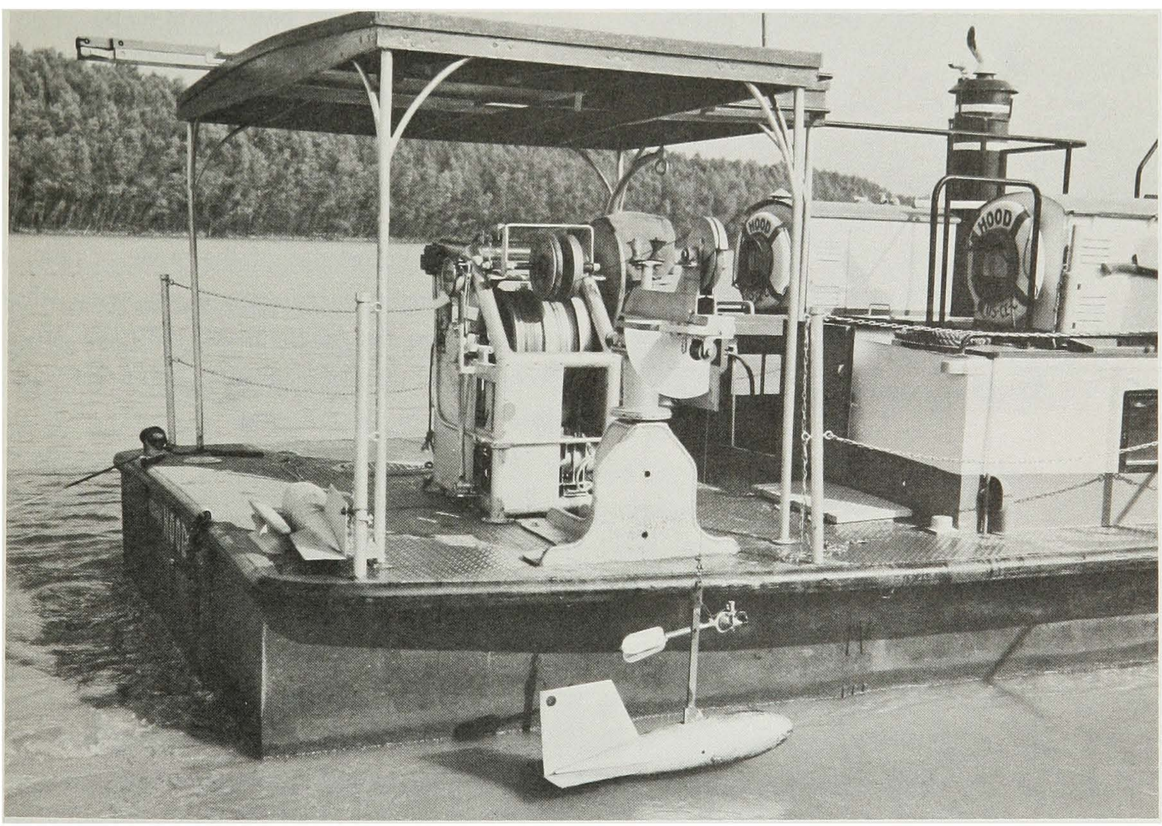

Figure 9. Discharge boat Hood with current meter equipment alongside

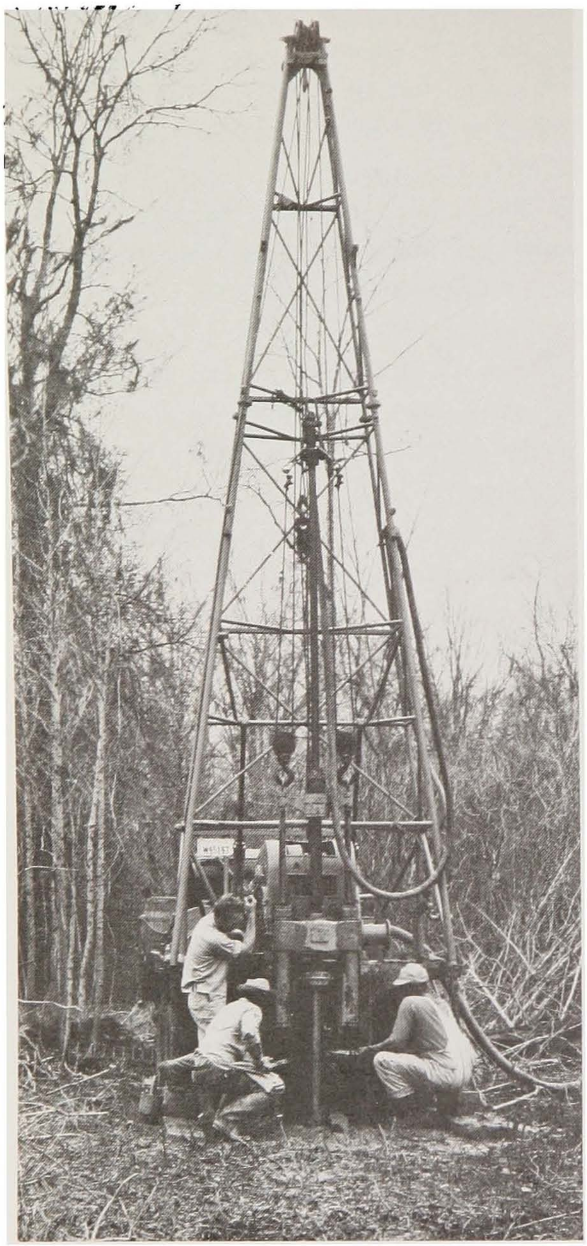

Figure 10. Truck-mounted rotary drill rig for soil sampling

be used to establish and operate reporting networks of river and rainfall stations. Ten of these cooperative networks are now in operation within the Lower Mississippi Valley Division. Additional sums are transferred, annually, to the Weather Service to assist in maintaining a hydroclimatic network comprising recording and nonrecording precipitation gages.

Coincidently with the earliest studies of the lower basin, the composition of the underlying beds was explored by means of soil borings. Some of these were made to prove or disprove theories about the nature of the bottom of the river. Others were made in conjunction with levee location studies and similar investigations. Increasing recognition of the importance of thorough foundation exploration has led to the practice of making many borings at proposed sites for levees, revetments, and other structures (see figure 10), followed by appropriate laboratory analyses of boring samples. Similar examinations are made of proposed sources of concrete aggregate and of borrow for earthfill. Many deep borings have also been made in the valley by other agencies for various engineering purposes; for water supplies; and for petroleum exploration. The records of such explorations have been of inestimable value in general planning activities, and particularly in geological studies. The objectives of these studies are to obtain knowledge of the mode of origin and the depositional environments of sediments, which is prerequisite to the prediction of soil types and their effects on foundation conditions, and to estimate the future behavior of the river.

Hydrographic maps prepared under the direction of the Mississippi River Commission depict a flow line ("standard mean low water" or equivalent terminology) which has been used as a zero reference plane for depth contours in comparing cross-sectional elements, and to show channel conditions. As adopted in 1933, it represented the average of low water elevations for a period of 40 years. At that time, there had been no major changes in the channel for a considerable period and, generally, the data, when adopted, represented reasonably well the flow lines expected for low water flows. Subsequent to 1933, as a result of construction of numerous cutoffs on the river, the low water flow line dropped considerably throughout a long stretch of the river. Where this happened, the depths and areas, based on the previously established mean low water, did not properly represent those elements for actual low water flows. To remedy this, in 1947, a variable low water reference plane, based on mean low water flow, was substituted for the earlier 40-year average of low

water elevations. The new flow line represented approximately the actual flow line expected for low water flow. It was conceded that adjustments might be necessary from time to time if major changes occurred in the river, or if cumulative changes made it advisable. An adjustment was made in 1962, but, because of the relatively stable conditions that had existed for the preceding 10 to 15 years, the revision of 1962 was established on the basis of the average of the minimum stages and flows for those years and is now termed the "average low water plane."

In 1838, Captain A. Talcott, Corps of Engineers, while making a survey of the mouths of the Mississippi, took samples of the surface and below-surface water in Southwest Pass, which he analyzed and compared. Thus began the investigation of the action of sediment in the lower Mississippi River. The years following saw many observations made at scattered points along the lower river, including those by Humphreys and Abbot* made at Carrollton in 1851-53 and at Columbus in 1858. Sampling procedures and methods of analysis for many years varied widely, and not unexpectedly differences of opinion developed on the validity of some of the conclusions. The overall objective was an understanding of the phenomenon of the power of running water to entrain solids of various and significant particle sizes and of densities superior to its density. Following creation of the Mississippi River Commission in 1879, these observations were continued, with greater standardization of procedures than had obtained up to that time. The results of these observations are included in several Commission reports and in the Annual Reports of the Chief of Engineers. A summary of sediment investigations on the Mississippi River and its tributaries prior to 1930 was published in 1931 as Paper H of the Waterways Experiment Station, and a report on the methods employed and results obtained in the 1930-31 sediment investigations is contained in Paper U of the Waterways Experiment Station, also published in 1931.

A suspended sediment-sampling program was initiated in 1949 to study the effect of bank-stabilization works on the suspended loads transported by the Mississippi River and its tributaries. Following the procedures developed under the cooperative project sponsored by the Subcommittee on Sedimentation, Federal Interagency River Basin Committee, study ranges were established, mainly within the New Orleans District, and standard sampling methods and techniques were followed. Sediment-sampling ranges were established in October 1949 on the Mississippi River at Baton Rouge (mile 230.0); in October 1950 on the Atchafalaya River at Simmesport (mile 6.3); and in September 1951 on the Red River at Alexandria (mile 114.5). Bed-material sampling was initiated at the Simmesport range in 1954; at the Baton Rouge range in 1955; and at the Alexandria range in 1958. The frequency of observations is dependent on the magnitude of flow. Measurements are made at 2- to 7-day intervals to define and rate the sediment transport during high flows, and at biweekly intervals during low-flow periods.

The sampling ranges are so located as to develop the quantity of suspended sediment transport at or near established discharge ranges. The sampling program in the main streams and tributaries consists of obtaining either point or depth-integrated samples, using either the U. S. P-46 or U. S. P-50 sampler. Other samplers used are the U. S. P-61 and the U. S. B. M. 54. The method of sampling at each location depends on the cross-sectional area, the stream depth, and the magnitude of discharge or velocity. Point sampling is usually performed in the deep main streams, and depth-integrated sampling, in the shallower tributary streams. In the Mississippi River, samples are taken at eight verticals in the cross section; at five in the Atchafalaya River; and at three in the Red River. Generally, five point-sampling depths are assigned to each vertical for load determinations, with an additional sample taken approximately 3 feet

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* Report of Captain A. A. Humphreys and Lieutenant H. L. Abbot of the Army Topographical Engineers on "The Physics and Hydraulics of the Mississippi River," made in 1861.

above the bed to enable better definition of sediment distribution near the bed. Depth-integrated samples are taken in the Red River during low-flow periods because of the low sediment concentration. Bed-material samples are taken at each vertical in the main streams at the times of sampling of suspended sediment.

The main-stream sampling program has been continuous since 1949. However, the Mississippi River sampling range which was located at Baton Rouge was moved to Red River Landing (mile 299.5) in 1957, and then to Tarbert Landing (mile 304.1) after the closure of Old River in 1963. A summary of measured suspended sediment loads at several main river stations is shown in table 1.

A program of observing and recording hydrologic-hydraulic and sedimentation data has been in progress in the Atchafalaya River Basin since 1916. The information acquired prior to 1951 is assembled in the report, *The Atchafalaya River Study,* published by the Commission in 1951. A 1932 bed-material survey in the Atchafalaya Basin recorded 109 thalweg samples in the main channels and auxiliary channel systems. A discussion of the results is contained in Waterways Experiment Station Paper No. 17, *Studies of River Bed Materials and Their Movement, with Special Reference to the Lower Mississippi River,* published in 1935. In 1951, 27 bed-material samples were taken in the main channel at locations similar to those of the 1932 survey for comparative information on the specific gravity, median range diameters, and grain-size distribution of the channel bed material. Additional bed-material samples were obtained in 1959, 1960, 1961, and 1965 at 30 stations in the main channel between the head of Whiskey Bay Pilot Channel and Six Mile Lake, and elsewhere in the basin, that were established to observe distribution of flow. The analysis reports included specific gravity and grain-size data of the bed material, and related discharge data. Suspended sediment point samples have been taken in the Atchafalaya River at Simmesport, Louisiana, since 1950 at a frequency of twice monthly during normal-flow periods, and weekly during high-flow periods. Daily samples taken since 1951 provide the concentration data needed to compute the day-by-day suspended sediment loads. Suspended sampling was performed during high flows at the two Atchafalaya Basin outlets in 1950, 1951, 1955, and 1957 at discharge ranges in Berwick Bay and Wax Lake Outlet. Observations at these ranges were resumed in December 1964 to develop suspended sediment-discharge rating curves for use in studies of a proposed central channel plan and dredging program. Overbank sedimentation ranges were established across the Atchafalaya Basin in 1932 to facilitate study of the progressive deposition following inundations by floodflows. There are 32 of these cross-basin ranges, and they are resurveyed at approximately 5-year intervals. Hydrographic surveys of dredge reaches of the Atchafalaya River channels are made at intervals of 2 years to ascertain the scour and fill taking place therein.

In connection with the construction of the closure of Old River, a suspended sediment range was established at the head of the Atchafalaya River at Barbre Landing, and observations were made from August 1962 to May 1963. Upon completion of the Old River control structure, inflow, outflow, and hydrographic ranges were established to study the amount of sediment being diverted from the parent stream and to observe any changes within the outflow channel.

Suspended sediment observations have been made intermittently on the Yazoo River at Greenwood, Mississippi, and in Macon Lake and Ditch Bayou near Lake Village, Arkansas. Channel ranges have been established on outlet channels below flood control reservoirs, and on all streams where major channel improvements have been made, in order to study, by means of periodic resurveys, resultant changes in channel regimen.

An important consideration in design of storage reservoirs is allowance for loss of capacity through deposition of sediment introduced by tributary inflows. Periodic resurveys of storage areas of the five

Table 1

Summary of Measured Suspended Sediment Loads at Main River Stations

Water Year (Oct-Sep)	*Total Measured Sediment Load (in 1,000 tons)*	*Sand-Silt Ratio**				*Water Year Discharge (1,000 DSF)*	*Average Sediment Concentration (in ppm)*
		Sand (in 1,000 tons)	*%*	*Silt (in 1,000 tons)*	*%*		
	Atchafalaya River at Simmesport, Louisiana						
1951-1952	196,460	48,890	25	147,570	75	80,800	900
1952-1953	135,230	28,440	21	106,790	79	56,960	880
1953-1954	54,130	13,110	24	41,020	76	31,980	627
1954-1955	93,360	24,080	26	69,280	74	50,425	686
1955-1956	67,175	15,540	23	51,730	77	49,080	507
1956-1957	225,474	55,700	25	169,774	75	74,059	1,126
1957-1958	214,390	48,082	22	166,308	78	89,413	887
1958-1959	83,230	20,944	25	62,286	75	55,729	553
1959-1960	131,878	24,153	18	107,725	82	69,333	704
1960-1961	133,372	40,524	30	92,848	70	76,814	643
1961-1962	151,913	57,675	38	94,238	62	88,881	633
1962-1963	44,876	8,610	19	36,266	81	47,060	353
1963-1964	58,132	11,358	20	46,774	80	33,112	650
1964-1965	109,971	28,777	26	81,194	74	66,448	619
1965-1966	83,689	19,554	23	64,134	77	51,024	607
1966-1967	54,451	7,195	13	47,255	87	57,327	352
1967-1968	110,513	19,566	18	90,947	82	80,176	510
1968-1969	119,904	27,444	23	92,460	77	83,292	533
	Lower Mississippi River at Baton Rouge, Louisiana**						
1949-1950	548,330	107,770	20	440,560	80	245,200	828
1950-1951	575,280	67,600	12	507,680	88	224,810	947
1951-1952	408,390	73,820	18	334,570	82	200,660	754
1952-1953	212,580	28,920	14	183,660	86	142,200	552
1953-1954	107,730	14,090	13	93,650	87	88,660	449
1954-1955	211,490	39,930	19	171,550	81	137,460	570
1955-1956	161,220	25,920	16	135,300	84	127,530	468
1956-1957	291,388	53,043	18	238,345	82	172,875	624
1957-1958	325,774	95,203	29	230,571	71	195,653	616

(Continued)

* The sand fraction is the material retained on the No. 230 sieve (0.062 mm). The silt fraction includes all of the fine material passing the No. 230 sieve.

** Measurements were made at Baton Rouge until 1 Jan 1958, then at Red River Landing until 1 Oct 1963, and at Tarbert's Landing thereafter.

Table 1 (Concluded)

Water Year (Oct-Sep)	Total Measured Sediment Load (in 1,000 tons)	Sand-Silt Ratio: Sand (in 1,000 tons)	%	Silt (in 1,000 tons)	%	Water Year Discharge (1,000 DSF)	Average Sediment Concentration (in ppm)
		Lower Mississippi River at Red River Landing, Louisiana**					
1958-1959	230,504	78,693	34	151,811	66	129,253	660
1959-1960	318,234	77,219	24	241,015	76	163,850	718
1960-1961	231,754	71,471	31	160,283	69	168,133	510
1961-1962	264,031	94,037	36	169,994	64	191,007	512
1962-1963	100,397	23,770	24	76,627	76	105,125	353
1963-1964	125,189	17,836	14	107,353	86	122,965	377
1964-1965	201,653	43,683	22	157,970	78	150,152	497
1965-1966	148,341	38,159	26	110,182	74	123,918	443
1966-1967	112,283	16,986	15	95,297	85	131,861	336
1967-1968	158,132	39,490	25	119,642	75	162,971	362
1968-1969	165,527	38,959	24	126,568	76	167,999	365
		Red River at Alexandria, Louisiana					
1951-1952	39,560	6,450	16	33,110	84	8,460	1,730
1952-1953	43,760	11,900	27	31,860	73	12,550	1,290
1953-1954	16,490	3,130	19	13,360	81	5,910	1,030
1954-1955	21,830	3,590	16	18,240	84	7,340	1,102
1955-1956	13,400	2,210	17	11,190	83	4,380	1,132
1956-1957	82,385	16,950	21	65,432	79	16,779	1,817
1957-1958	95,623	15,279	16	80,344	84	18,473	1,915
1958-1959	13,565	4,164	31	9,401	69	6,832	735
1959-1960	31,939	6,231	20	25,708	80	9,821	1,204
1960-1961	46,957	12,199	26	34,758	74	12,735	1,365
1961-1962	45,582	10,906	24	34,676	76	12,515	1,349
1962-1963	9,818	2,574	26	7,244	74	4,992	728
1963-1964	11,445	1,930	17	9,516	83	4,201	1,008
1964-1965	20,620	3,939	19	16,681	81	6,856	1,818
1965-1966	32,063	6,805	21	25,257	79	8,048	1,476
1966-1967	15,378	2,654	17	12,724	83	6,795	838
1967-1968	70,312	20,990	30	49,322	70	16,184	1,608
1968-1969	59,887	16,654	28	43,234	72	14,815	1,497

** Measurements were made at Baton Rouge until 1 Jan 1958, then at Red River Landing until 1 Oct 1963, and at Tarbert's Landing thereafter.

reservoirs included in the Mississippi River and Tributaries Project, supplementing the preimpoundment surveys, are the bases for calculation of the actual extent of filling for the respective periods that these reservoirs have been in service. When Wappapello Reservoir, on the St. Francis River above Poplar Bluff, Missouri, was resurveyed in 1964, it was found that, for the 24 years since initial impoundment, sediment deposition totaled 11,839 acre-feet, equivalent to an annual deposition of 500 acre-feet, or 0.414 acre-foot per square mile of sediment-contributing area. The loss in flood control pool storage for the period was 1.89 percent, by volume, or an average annual loss of 0.08 percent. Sardis Reservoir, on the Little Tallahatchie River near Sardis, Mississippi, completed in 1939, showed by the resurvey of 1960 that sediment deposition totaled 20,564 acre-feet, equivalent to an annual deposition of 998 acre-feet, or 0.687 acre-foot per square mile of sediment-contributing area. The loss in flood control pool storage for the 21-year period was 1.31 percent, equivalent to an average annual storage loss of 0.08 percent. Arkabutla Reservoir, on the Coldwater River near Arkabutla, Mississippi, completed in 1941, showed by the survey of 1962 that sedimentation amounted to 12,240 acre-feet, an average annual deposition of 588 acre-feet, equivalent to 0.620 acre-foot per square mile of sediment-contributing area. Flood control pool storage loss, due to the sediment deposition, was 2.33 percent, an average annual storage loss of 0.11 percent. The 1961 sediment survey of Enid Reservoir, on the Yocona River near Enid, Mississippi, completed in 1951, showed that after 9.8 years of reservoir operation, the conservation and flood control pools had lost a volume of 2,829 acre-feet. The total volume lost in the reservoir was 0.43 percent of its original capacity, an average annual sediment deposit of 288 acre-feet, equivalent to 0.558 acre-foot per year per square mile of drainage area. In 1965, a survey of Grenada Reservoir, on the Yalobusha River near Grenada, Mississippi, completed in 1954, showed that in 11.8 years of operation of that reservoir, the conservation and flood control pools had lost 17,377 acre-feet, or 1.30 percent of the reservoir's original capacity, an average annual sediment deposit of 1,469 acre-feet. This is equivalent to 1.205 acre-feet per year per square mile of drainage area.

Cutoff Investigations

Elliott commented that natural cutoffs are a characteristic of alluvial streams, and pointed out that there is evidence of the occurrence of numerous cutoffs antedating the exploration of the lower Mississippi. It is believed that they usually took place during very high river stages, when flows scoured out channels across the narrow necks of overdeveloped bends. Proposals to construct artificial cutoffs on the lower Mississippi River were made as early as 1850. Although engineers were not agreed as to their effects, many concurred generally in the view expressed by Humphreys and Abbot in their Delta Survey that cutoffs increased downstream flood heights. Such belief and observation of natural cutoffs led the Mississippi River Commission in 1884 to take a stand against cutoffs. This policy had support for practical reasons—the Commission had neither funds nor dredging equipment with which to make artificial cutoffs or to control their development. Moreover, until passage of the Flood Control Act of 1917, appropriation of funds by Congress was generally restricted to works in aid of navigation. Works solely for flood control were prohibited, and any benefit to flood control from works designed to aid navigation was considered incidental. Natural cutoffs, likewise, were opposed because they were believed to have deleterious effects, providing only temporary lowerings of flood stages, but including undesirable channel changes extending both upstream and downstream. Cutoffs were not favored as a flood control device because it was generally thought that the temporary stage lowering immediately above the cutoff would be offset by an increase in flood heights below. Until 1928, the Mississippi River Commission policy

of preventing the occurrence of cutoffs prevailed, and measures, such as construction of dikes and revetments, were taken to forestall impending cutoffs.

Although proposals that the lower Mississippi River be improved by artificial cutoffs had recurred over a period of many years, no solution to the problem of how to execute and control work of such magnitude had been developed. It remained for Major General Harley B. Ferguson (then Colonel, Corps of Engineers) to propose, in 1930, a workable plan of procedure. Instead of constructing a complete cutoff in the dry and then diverting the river through it, as had been done in Europe, he proposed to make only a pilot cut. By doing so, the high velocities and increased flood stages downstream from the cutoff that had resulted from European practice would be avoided, and the slope adjustment that followed shortening of the river would be spread over a period of years.

During the low water season of 1929, there occurred an event at Yucatan Bend, about 40 miles downstream from Vicksburg, that was to help measurably in formulation of the cutoff program begun a few years later. It was the first cutoff permitted to occur on the lower Mississippi since 1884. Prior to 1929, the mouth of the Big Black River was located immediately below Yucatan Bend. Above the mouth, the channels of the two streams gradually approached each other as a result of bank caving. With the purpose of limiting enlargement of the Big Black channel in case of a cutoff, a mattress had been placed across its channel below the point of impending failure. A breakthrough about 2-1/2 miles above the mouth occurred late in 1929, and the segment of the former Big Black channel, now the cutoff channel, began to enlarge. The mattress was flanked at both ends and became ineffective. Two years later, it was estimated that the channel was passing only 40 percent of the total Mississippi River discharge. The former Big Black mouth was some 12 miles from the breakthrough by way of Hard Times Bend, and the entire fall around the bend became concentrated in the 2-1/2-mile Big Black channel. After two flood seasons, the crooked little valley of Big Black River had become a wide and nearly straight cutoff channel with ample depth for navigation. By April 1932, it was carrying 60 percent of the river's flow, and the rate of fall was almost the same across the cutoff as above and below it. At the same time, the old channel around Hard Times Bend had deteriorated, and, in November 1933, during a low river stage, the entire main-stem flow was passing through the new cutoff. The Yucatan incident demonstrated the superiority as a cutoff route of a narrow channel a mile or two in length to a short cut across a narrow neck of land, and that such an occurrence was not detrimental to the river's regimen.

General Ferguson had begun a comprehensive study of cutoffs on the lower Mississippi River in October 1930, during the time he was serving as Division Engineer of the South Atlantic Division in Norfolk, Virginia. The study was aimed at making major flood-stage reductions and stabilizing the banks of the new channel by revetment of banks. The project adopted in 1928 contemplated no cutoffs, and there existed among river officialdom an attitude of hostility toward anything that might tend to alter the adopted plan in any way, which, of course, discouraged study of new approaches to the flood control problem. Nevertheless, General Ferguson had, by 22 November 1930, completed a memorandum report recommending cutoffs in the 370-mile reach between the mouths of the White and Old Rivers. This report was submitted to the Board of Engineers for Rivers and Harbors later that year and was approved by the Board in February 1931. Upon taking office as President of the Mississippi River Commission in June 1932, General Ferguson immediately embarked upon the cutoff program (see figure 11). Wherever conditions permitted, the program followed the Yucatan precedent, and aimed at shortening the river without any attempt at straightening it. A moderate curvature, in fact, was thought to be essential for preservation of a deep navigable channel as well as for channel-stabilization purposes. The principal purpose

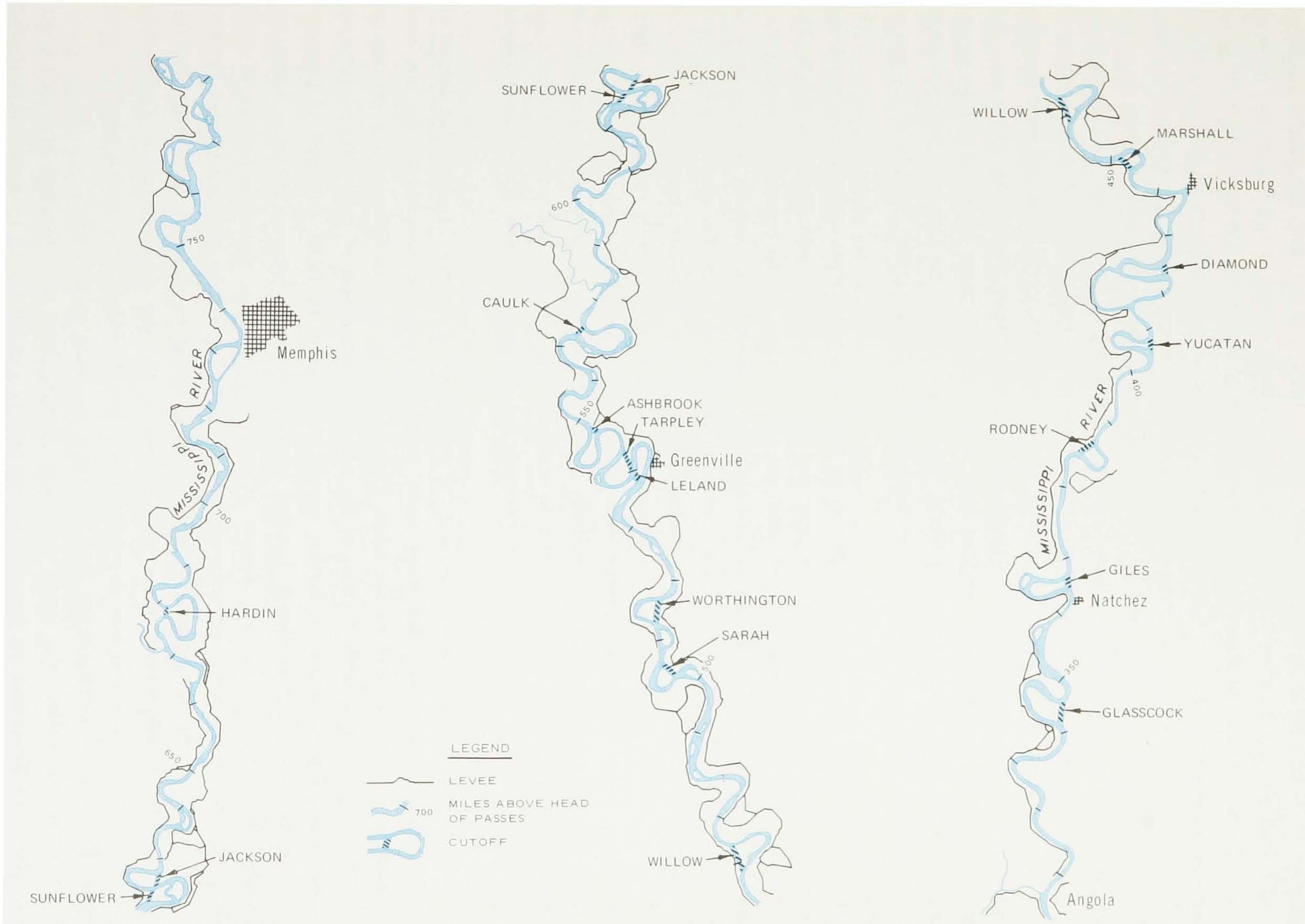


Figure 11. Cutoffs between Memphis, Tennessee, and Angola, Louisiana

was lowering of flood stages, with planning aimed at utilizing, insofar as possible, the river's energy to perform the major part of the work of excavating new channels and of filling those to be abandoned.

The cutoff program was vigorously prosecuted. By 1939, 11 cutoffs, located between the mouth of the Arkansas River and Baton Rouge, had been opened. They, together with the natural cutoffs at Yucatan and Leland, shortened the river, measured at bankfull stage, a total of 115.8 miles over a former river distance of 330.6 miles. The *History of the Improvement of the Lower Mississippi River for Flood Control and Navigation—1932-1939,* by General Ferguson, includes an explanation in detail of the methods used in this improvement work; a description of operations in the several reaches; the construction plant used; and the results obtained. In 1941 and 1942, three additional cutoffs were made between the mouth of the Arkansas and Memphis. Including channel dredging consisting of development of certain chutes which fitted into the new river alignment better than did the main channel, these 16 cutoffs shortened the former low water river length about 25 percent, or 170 miles. In 1945, about 16 miles upstream from Memphis, at mile 752, there occurred a natural cutoff through Brandywine Chute, which was aided by dredging. This cutoff and the three artificial ones in the reach between Memphis and the mouth of the Arkansas River were developed during World War II years, when the Corps of Engineers could assign only a skeleton force to maintain the navigable channel. Consequently, records of the rate of development are sparse.

Cutoffs shortened the river and also improved its alignment; but, unless controlled by stabilizing the banks, channel meander would occur and cause the river to tend to regain its former length. The losses in valley storage due to stage lowering were more than offset by the increases in velocity due to steepening of the slopes and by leaving the old bendway channels open, thereby allowing entry of floodwaters and flooding of the land back to the levees as formerly occurred. The shortening by cutoffs and chute enlargement eliminated the need to maintain many miles of abandoned bendway channel and previously active revetment, and increased channel-discharge capacity, consequently reducing flood stages. On the debit side, channel deepening upstream from cutoffs caused some local bank caving, with sliding and destruction of several revetments. By substantially reducing flood stages, the cutoff program effected great savings in the cost of raising the levee system to confine the project flow and permitted elimination of the floodway on the west side of the river between the Arkansas and Red Rivers, contemplated by the project authorized in 1928.

Despite clearly identifiable benefits, fulfilling the predictions of General Ferguson, the subject of cutoffs remained one of controversy for many years, involving navigation interests on the one hand and the proponents of flood control on the other. Perhaps due, in part, to differences of opinion on the merits of the program, and partly because of the necessary curtailment of civil works construction during the war years, few proposals for further cutoffs were made. In 1938, the Chief of Engineers conceded the merits of a cutoff at Slough Landing Neck, in the reach between Hickman, Kentucky, and Tiptonville, Tennessee, but did not approve of making a cutoff at that time because of other considerations. In 1947, the subject was reopened and, in a letter report, the Memphis District Engineer expressed grave concern over the navigation difficulties that would be experienced between the time of making the cutoff and adjustment of the river regimen to the new slope conditions. The possible adverse effect on existing revetments was also pointed out. The Mississippi River Commission concurred in the District Engineer's recommendation that no action be taken at that time.

Again, in 1950, the matter of a cutoff at Slough Landing Neck was discussed in a preliminary examination report, and the conclusion was reached that neither a cutoff nor an alternative plan utilizing a controlled weir could be justified economically. Moreover, one effect of such a cutoff would be to

lower the low water surface for some distance upstream, which might adversely affect the navigation depths at the lowest Ohio River lock and dam and over a rock ledge near Thebes, Illinois, on the upper Mississippi River, entailing greatly increased maintenance costs for a 9-foot navigation channel and possibly preventing the ultimate attainment of a 12-foot channel. Although further investigations of a cutoff at this location were not made in preparing the Mississippi River and Tributaries Comprehensive Review Report submitted in 1959, the report embodied a discussion of proposals made, and concluded with the statement that a cutoff at Slough Landing Neck was not favorably considered and was not included in the broad plan of channel improvement. The report also discussed a cutoff at Australia Point, as proposed by local interests, and concluded that interference with the planned operation of the Morganza Floodway and other objections required that no action be taken to create a cutoff at this location.

In 1961, an overall review was made of the long-range channel-stabilization program, with the objective of identifying possible future requirements, including cutoffs to be made before the lands required for them were preempted for other purposes, and of designing the best possible alignment for stabilization purposes and of avoiding, insofar as practicable, expenditures for construction of revetment which would not be required in the future because of changes in river alignment. The review developed the need to consider the feasibility and advisability of constructing additional cutoffs. Earlier alignment planning programs had necessarily been concerned mainly with protecting levees, floodwalls, and other flood control structures from the consequences of uncontrolled channel meanders. By 1961, construction had progressed to a stage such that it was possible to give greater attention to promotion and maintenance of good alignment. Accordingly, late in 1961, a study was begun to ascertain the relative merits of cutoffs across existing major meander loops. No new basic data were procured; available maps and subsurface information were used in the analysis. Hydraulic studies of selected alignments were made to estimate the effects of changes in alignment on floods and low water stages and velocities in those reaches. The effects of such changes on navigation, existing facilities, and communities in the area were studied, and flood control and navigation benefits were evaluated.

In all, 12 studies of meander-loop cutoffs were made. Three of them were site locations below Baton Rouge (Point Clair, Plaquemine Point, and Australia Point); three, between Baton Rouge and Natchez (Thomas Point, Fancy Point-Profit Island, and Jackson Point); and six, between Greenville and Cairo (Old White River, Nebraska Point, Opposite Caruthersville, Donaldson Point-Toneys Towhead, and Slough Landing Neck—uncontrolled and controlled).

At Point Clair, the cutoff studied would extend from about mile 188 to mile 200 above the Head of Passes (1937 mileage); would be approximately 3.6 miles long; and would shorten the river about 8.3 miles. Ultimate stage reductions, including future channel degradation, projected upstream for the 1956 project flood, gave 0.94 foot at the entrance to the Morganza control structure, and 0.71 foot at the entrance to the Old River control structure. The computed reductions for low water were essentially zero. The lowering of flood stages would obviously reduce the capacities of the two major structures. Although corrective measures to insure retention of the design capacities could be undertaken, the exact scope could not be determined until the structures had been operated in a major flood. In any event, any such alterations to these large structures would be very costly. Moreover, as the point has been highly developed, rights-of-way for the cutoff, spoil area, and levee along the east side of the cutoff would also be very costly, as would severances and relocations. The total construction cost, including modifications of the Morganza and Old River control structures, was estimated to be $47,140,000, which, on the basis of a 50-year life, would be equivalent to an annual cost of $1,777,000. The annual benefits were estimated to be $1,213,000, of which navigation benefits were estimated to be 66-1/2 percent,

resulting in a benefit-cost ratio of 0.7. Because of the many adverse and questionable aspects, together with the lack of economic justification, it was concluded that Point Clair does not lend itself to construction of a cutoff. It was also felt that, although the present alignment is not the most desirable, it is tolerable and can be maintained.

Detailed study was not given to a cutoff across Plaquemine Point because a satisfactory alignment for such a channel would sever an existing oilfield, and would require relocation of the town of Sunshine. It was concluded that a cutoff here would offer little, if any, advantage over one across the base of Australia Point, but would be more costly to construct. Consideration was given to a double cutoff across Australia Point and Plaquemine Point, as discussed later.

The alignment considered for a cutoff across Australia Point would require, also, a point-way channel across the bar and tip of Plaquemine Point, and would necessitate realignment of the river between approximate mile 206 and mile 221 above the Head of Passes (1937 mileage), shortening the river from 13.5 miles to 4.5 miles. Ultimate stage reductions, including future channel degradation, projected upstream for the 1956 project flood were 0.94 foot and 0.72 foot, respectively, at the entrances of the Morganza and Old River control structures. The computed reductions for mean low water were 0.18 foot and 0.09 foot, respectively. Although the lands that would be severed on Australia Point were unprotected cutover woodlands, a realignment and setback of the levee across the neck of Australia Point would be necessary, and the levees at the tip of Plaquemine Point would have to be relocated.

In addition to an expected increase in maintenance-dredging requirements at the entrance to Port Allen Lock and in the Baton Rouge Harbor, there would also be the question of the reduction in design capacities of the Morganza and Old River control structures due to the reduction in flood stages which, as in the case of the cutoff at Point Clair, could not be determined until the structures had been operated in a major flood. The total construction cost was estimated to be $29,083,000, including remedial works for the Morganza and Old River control structures. On the basis of a 50-year life, the annual cost would be $1,092,600. The estimated annual benefits were $1,221,000, of which 81 percent were based on transportation savings. The indicated benefit-cost ratio was 1.1. The conclusion from the study was that some modification to the alignment of the cutoff should be considered, but that further studies, supplemented by model tests and actual operating experience at Morganza and Old River, are required before construction should be considered.

As an alternative to separate cutoffs across each point, a study was made of a plan combining cutoffs across both Australia and Plaquemine Points. The cutoffs would extend approximately from mile 204 to mile 220.5 above the Head of Passes (1937 mileage), and would shorten the river from 16.7 miles to 5.9 miles. Ultimate stage reductions, including future channel degradation, projected upstream for the 1956 project flood, were 1.38 feet and 1.06 feet, respectively, at the entrances to the Morganza and Old River control structures. The computed reductions for mean low water were the same as those for the separate Australia Point cutoff. Also, as in the case of the separate cutoff, the lands that would be severed on Australia Point were unprotected cutover woodlands, but a setback levee would be required across the neck, and also across Plaquemine Point. Likewise, there would be the possibility of increased maintenance-dredging requirements at the entrance to Port Allen Lock and in the Baton Rouge Harbor, and there would be concern as to the reduction in design capacities of the Morganza and Old River control structures due to the reduction in flood stages. The total construction cost, including remedial works at the control structures, was estimated to be $58,217,000, with average annual charges of $2,271,000. The estimated annual benefits were $1,624,000, of which 71 percent were based on transportation savings, giving a benefit-cost ratio of 0.7. It was concluded that, although

the proposed cutoffs do not appear to be presently justified and could present problems in the Baton Rouge Harbor area, the great improvement in alignment that would result, together with the slack water harbors that could be provided, warrants a more detailed study after modifications to the Morganza and Old River control structures can be accurately determined.

The cutoffs studied at Thomas Point would extend from about mile 234 to mile 243 above the Head of Passes (1937 mileage), and would shorten the river from 8.6 to 2.8 miles. Ultimate stage reductions, including future channel degradation, projected upstream for the 1956 project flood, were computed to amount to 1.1 feet and 0.8 foot, respectively, at the entrances of the Morganza and Old River control structures. The computed reductions for mean low water were 0.07 foot and 0.02 foot, respectively. The proposed pilot cut followed by natural enlargement of the channel, combined with changed patterns along the Baton Rouge waterfront, suggested as a possible consequence greatly increased maintenance dredging. As in the studies of the cutoffs below Baton Rouge, there was the question of the effect of the reduced stages on the design capacities of the Morganza and Old River control structures. The total cost of construction of the cutoff, including an allowance for remedial works at the control structures, was estimated to be $16,035,000. The estimated annual cost would be $1,024,000, and the annual benefits were estimated to be $747,100, giving a benefit-cost ratio of 0.7. Considering the possibility that planned revetments in the meander loop will be completed before operating experience can be gained at the Morganza and Old River control structures, the lack of economic justification would be further accentuated. Furthermore, the highly developed harbor area just below the cutoff site poses a serious problem. These factors and the effect on the Morganza and Old River control structures led to the conclusion that the cutoff should not be constructed and that future efforts should be devoted to easing the bendways in the meander loop.

The cutoff at Fancy Point-Profit Island involved a reach of river containing split channels, caused by chutes, at two locations. The improvement studied would have extended through two chutes and across Point Menoir, from mile 245 to mile 258 above the Head of Passes (1937 mileage), and would have shortened the present channel about 3.5 miles. Including future channel degradation, ultimate stage reductions projected upstream for the 1956 project flood were estimated to amount to 0.58 foot and 0.49 foot, respectively, at the entrances of the Morganza and Old River control structures. The computed reductions for mean low water were 0.21 foot and 0.12 foot, respectively. As in the case of the downriver cutoffs considered, the lowering of the flood stages might necessitate costly alterations to the two control structures; in addition, a problem might be created at Old River due to reduction of the low water stage. The extent of alterations required could be determined only by actual operation of the structures. The estimated construction cost, including that of control-structure modifications, was $28,277,000. The estimated annual cost was $1,135,000. Navigation savings due to the reduction of 3.5 miles and savings due to decreased length of revetment were the chief bases for the benefits which were computed to be $632,000 annually, from which a benefit-cost ratio of 0.6 resulted. Due to the possible adverse effect on the Morganza and Old River control structures, the apparent lack of justification, difficulties in developing the cutoffs, and the questionable desirability of attempting to develop such a long straight reach of river, it was concluded that this site is not suitable for a cutoff.

The cutoff considered at Jackson Point would extend approximately from mile 321.5 to mile 333.5 above the Head of Passes (1937 mileage), and the sailing distance around the bendway would be shortened about 7.6 miles. These modifications would lower stages at the mouth of the Homochitto River more than a foot, causing a lowering and steepening of flow lines in the lower reaches of that river which would aggravate an already unsatisfactory condition. However, the primary concern here would be the

ability to hold the present downstream alignment of the main river, as a change in alignment near the entrance to the Old River control structures might adversely affect the diversion of flows. The estimated total cost of construction was $17,100,000, and, using a 50-year life, the annual charges would be $789,000. Benefits, consisting of estimated navigation savings and annual charges for revetment which would be eliminated in the existing bendway, totaled $887,000, from which the benefit-cost ratio was calculated to be 1.1. Although the project might appear to be favorable on the basis of the cost figures, the cost of controlling the alignment below the cutoff would be indefinite and in excess of that used in the estimate. Any adverse effect on the Old River control structure respecting its ability to pass its design flow would upset the entire flood control plan below Old River. It was concluded that the advantages that might result from construction of the cutoff did not justify the risk that would be involved.

The cutoff at Old White River envisioned an alignment following an existing secondary Mississippi River channel through Old White River and a chute thereof. The secondary channel was formed in October 1953, when the Mississippi River caved into the White River, making a new mouth for the White River. The cutoff would extend approximately from mile 583.5 to mile 590.5 above the Head of Passes (1937 mileage), and would be essentially a realignment of the river and an easing of curvature around Victoria Bend. It would shorten the river about 3.7 miles, but would not produce significant stage lowering. The construction cost was estimated to be $7,800,000, and, on a 50-year-life basis, the annual charges would be $440,000. The annual benefits, which included the annual charges for work that would be eliminated in the bendway if the cutoff were constructed, totaled $539,000, from which the indicated benefit-cost ratio was calculated to be 1.2. It was concluded that, because of inherent risks involved in constructing a cutoff at this location, the then current plan of stabilizing this reach should be continued.

The location studied for a cutoff at Nebraska Point is between approximate mile 807.5 and mile 819.5 above the Head of Passes (1937 mileage). The cutoff would be about 3.4 miles in length, and it would shorten the sailing distance by 9.0 miles. It would produce significant stage lowering for the project flood as far upstream as Caruthersville (mile 848.3, 1937 mileage). The estimated total cost of construction, including additional corrective and maintenance dredging, was $24,639,000, from which amount, using a 50-year life, an annual cost of $951,000 was derived. Most of the benefits accrued to navigation because of the shorter travel distance, and the total was estimated to be $850,000, making the benefit-cost ratio equal to 0.9. The existing alignment around Nebraska Point, although containing more curvature than desirable, is not unacceptable for navigation or stabilization. A great disruption to the channel alignment and the stabilization program would be experienced in the straight reach below the cutoff. Considering possible adverse effects, it was doubted that the net result of the cutoff at Nebraska Point would be an improvement of the channel alignment.

The site studied for the Opposite Caruthersville cutoff extended from mile 846.7 to mile 858.3 above the Head of Passes (1937 mileage). The cutoff would be about 4.7 miles long and would shorten the sailing distance by about 5.4 miles. Stage lowerings for the project flood were computed to extend upstream beyond New Madrid (mile 895.0, 1937 mileage). The estimated total cost of construction, reduced by deducting the cost of planned channel-improvement work in that reach, which would be eliminated, was $15,849,000. The equivalent annual cost was $633,000, which, when compared with annual benefits of $498,000, gave a benefit-cost ratio of 0.8. Because of the advanced stage of stabilization of this reach of river, possible adverse effects on Caruthersville, and other unfavorable factors, it was concluded that this cutoff should not be constructed.

The meander loop at Slough Landing Neck (see figure 12) is the longest one remaining on the

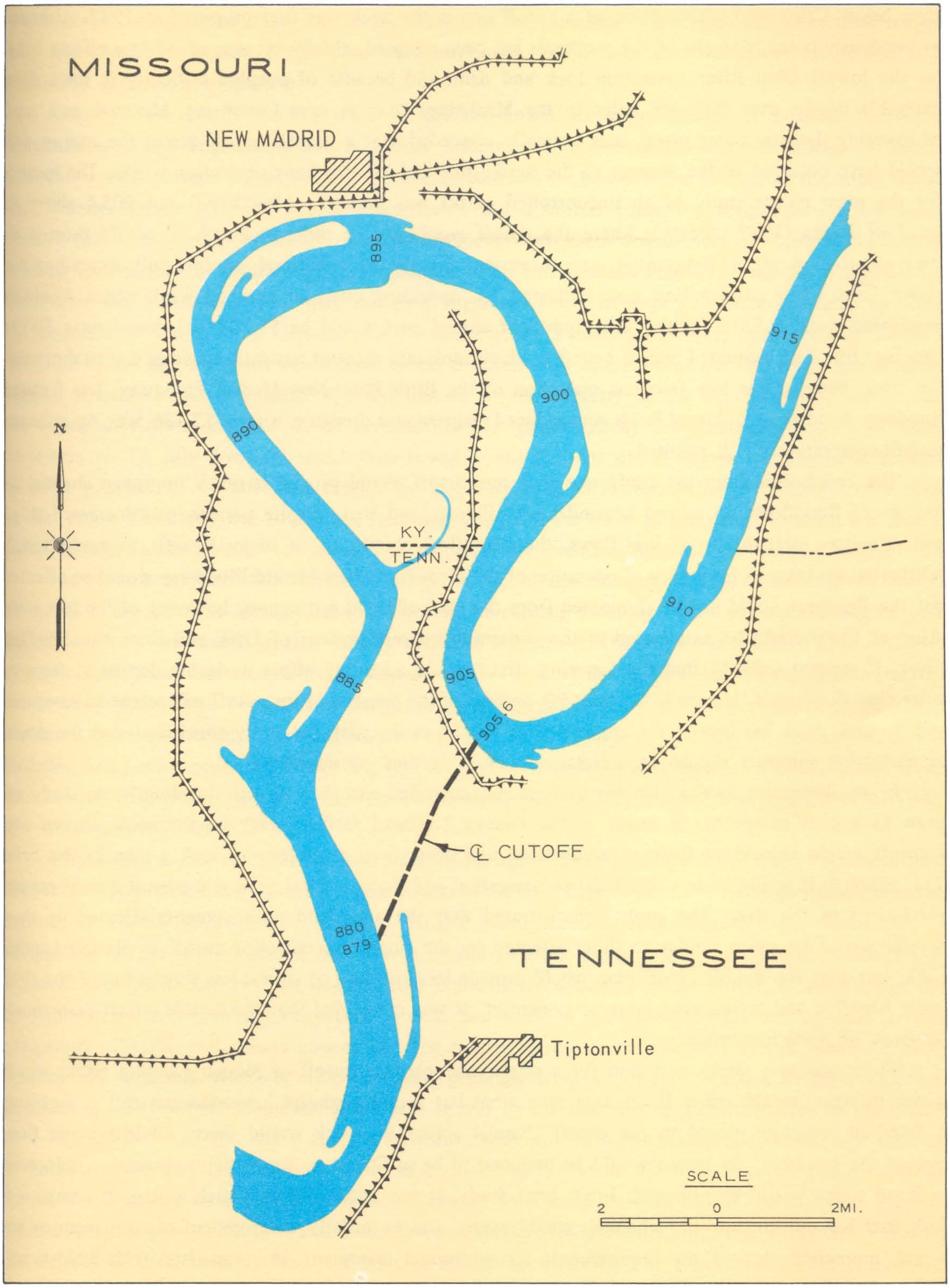


Figure 12. Slough Landing Neck meander

river below Cairo, and construction of a cutoff across the neck was first proposed in 1937. Although, as previously noted, not one of the proposals has been adopted, chiefly because of adverse effects feared on the lowest Ohio River navigation lock and dam, and because of possible difficulty in maintaining navigable depths over the rock ledge in the Mississippi channel near Commerce, Missouri, as a result of lowering the low water plane, it is generally conceded that a natural cutoff across the narrow neck would have occurred in the absence of the Bessie dike and existing bank-protection works. The location for the most recent study of an uncontrolled cutoff was between miles 879.0 and 905.6 above the Head of Passes (1937 mileage), where the cutoff would be 5.1 miles in length. It would shorten the river about 21.4 miles. Substantial stage lowerings for the project flood would result, extending well above Cairo. The construction cost, adjusted by deducting costs of planned work which would be eliminated, totaled $31,752,900. The equivalent annual cost would be $1,208,000, based on a 50-year structure life. The estimated annual benefits, which took into account navigation savings due to shortening the river, benefits for less frequent operation of the Birds Point-New Madrid Floodway, less frequent floodway flooding of unleveed lands, and reduced maintenance dredging, totaled $2,136,500. An indicated benefit-cost ratio of 1.8 resulted.

The conclusion from the study was that this cutoff would provide a much improved channel for passage of floodflows up to and beyond Cairo, Illinois, and that, despite permanently increased slopes and velocities, particularly at low flows, the net effect should be of major benefit to navigation. A substantial decrease in frequency of operation of the Birds Point-New Madrid Floodway would be effected, but the floodway could not be eliminated from the plan of flood protection. Lowering of the low water plane at Cairo could be anticipated in the contemplated replacement of Lock and Dam No. 53, Ohio River. It seemed unlikely that the lowering effect would adversely affect navigable depths at the rock ledge near Commerce, Missouri. As about 90 percent of the benefits of the cutoff will accrue to navigation and because there has been some opposition to cutoffs in the past, the study concluded that the desires of navigation interests should be ascertained before further consideration.

As an alternative to the plan for a single, uncontrolled cutoff at Slough Landing Neck, study was given to a plan comprising a cutoff across Toneys Towhead farther north on the neck, aligned with a cutoff across Donaldson Point. Consideration had been given previously to such a plan in the belief that, although it would be less beneficial to navigation and flood control, it would permit a more gradual adjustment of the river. The study demonstrated that the areas and improvements affected by these cutoffs would be quite similar to those affected by the single, uncontrolled cutoff at Slough Landing Neck, but that the double cutoff plan would provide less lowering of stages; less shortening of the river; lower benefits; and would cost more to construct. It was concluded that the double cutoff plan should be given no further consideration.

Study was also given to a plan for a single, uncontrolled cutoff at Slough Landing Neck, which, it was thought, would assure flood-stage reductions but would minimize low water navigation problems. A fixed-sill structure placed in the cutoff channel across the neck would divert all low water flows around the bendway. Its length would be designed to be sufficient to assure that appreciable reductions in flood stages would be obtained. From brief study, it was concluded that such a plan, in comparison with that for the uncontrolled channel, would assure a more orderly development of river regimen and would appreciably reduce the requirements for additional revetment, in comparison with what would be required for an uncontrolled cutoff. However, costs were not commensurate with benefits, and on the basis of experience with existing cutoffs, it was believed that large maintenance costs would be incurred in keeping the bendway open to navigation. There was also concern that a hazard to navigation

would occur during higher stages due to the draft into the approach of the fixed weir. For these reasons, cost and benefit estimates of this plan were not made, and it was concluded that no further study should be given this alternative.

Although the cutoff studies were of the reconnaissance type, making it possible that closer examination of the engineering and economic features might well result in minor changes, it seemed doubtful if such changes would modify the overall conclusions, based on the findings of the initial studies. The benefits sought included improved alignment and a shorter route for navigation, but the studies showed that construction of cutoffs in some instances might cause a worsening of alignment in adjacent reaches. Except for the Australia Point-Plaquemine Point (or Australia Point) site and the Slough Landing Neck site, the indications were that the river alignment could be improved more satisfactorily within the confines of the existing channel than by constructing a cutoff. However, further consideration of the sites below Baton Rouge would have to be deferred until operation of the Old River and Morganza control structures makes possible a determination of the capacity of the structures to pass the flows for which they were designed. These conclusions were confirmed by the Mississippi River Commission in session on 18 July 1962, at which time it was agreed that the site at Slough Landing Neck appeared to offer possibilities of sufficient magnitude to justify a detailed engineering investigation of a cutoff at that point. The study was authorized later that year, and the name of the cutoff location was changed from "Slough Landing Neck" to "Bessie," to reconcile the identification with that used by local interests.

The broad purpose of the detailed investigation was to determine whether it would be more desirable to stabilize the bend at Slough Landing Neck in its existing location, or to shorten the alignment by making one or more cutoffs in that vicinity and then stabilize it. The study was confined to an evaluation of the relative merits of alternative alignments of the channel in the New Madrid-Tiptonville reach. In determining their flood control and navigation benefits, flood and low water stages and velocities in the reach were calculated, then an analysis was made of the respective effects on navigation, existing facilities, and communities in the area. Surveys and soil investigations were made, as needed, to supplement data available from other studies. An economic analysis was made as a basis for estimation of navigation and flood control benefits.

A hydraulic model study of the plan selected for study was conducted at the Waterways Experiment Station to obtain indications of the possible effects of assumed degrees of cutoff development on velocities, current directions, water-surface profiles, channel configurations, channel-meandering tendencies, and navigability of the reach affected (see figures 13 and 14). The model was also employed to demonstrate sediment movement and channel development immediately upstream of the cutoff. It was likewise used to demonstrate river conditions expected to exist as a result of the cutoff construction to local interests, navigation officials, and others concerned. The model reproduced a 79-mile reach of Mississippi River channel and adjacent overbank area, extending generally from about a mile above Ridgely, Tennessee, to about 2 miles above Columbus, Kentucky. It was of the fixed-bed type, constructed to linear scales of 1 to 500 horizontally and 1 to 100 vertically, with provision for partial conversion to a sand bed to indicate scour and fill areas as a guide in further adjustment of the river channel. The riverbed and banks of the model were altered to reflect expected conditions after the cutoff was made, as estimated from a study of previous cutoffs and as indicated by model behavior. Public hearings were held to ascertain the desires of local interests and attitudes of navigation interests. The views of the District Engineers of the St. Louis and Louisville Districts were obtained on the effect of a cutoff at this location on projects in those Districts. The comments of the U. S. Public Health Service and the U. S. Fish and Wildlife Service concerning the effects of a cutoff on their interests in the area were obtained.

Figure 13. Aerial view of hydraulic model of proposed Slough Landing Neck (Bessie) Cutoff

Figure 14. Closeup of hydraulic model of proposed Slough Landing Neck (Bessie) Cutoff

Four plans were studied in some detail. One was of a spillway, or controlled cutoff, across the neck. This plan had been suggested previously as a possible means of providing sufficient flood lowering to justify abandonment of the Birds Point-New Madrid Floodway. Essentially, the plan would have provided a control structure that would pass a portion of the river's flow across the neck during flood stages, while maintaining the navigation channel around the bendway. Although this plan would assure an orderly readjustment of river regimen and would reduce the need for additional bank stabilization, a large amount of dredging would be required to maintain the navigation channel. The plan was found to be economically infeasible.

A second plan involved a double cut across Donaldson Point and the narrow part of Slough Landing Neck north of Bessie, as proposed in the 1962 reconnaissance study. It was apparent that the uneven development of the two cuts and the angle of approach of the river channel between the two cuts would result in serious problems during construction and development of the cutoff, which would create difficulties in controlling the cutoff channel alignment and give rise to major navigation difficulties between the two cuts. The principal benefits would be to navigation in the 18-mile shortening of the towing distance.

A third plan envisioned a cutoff across Donaldson Point. The study found that construction and development of a cutoff at this location would present no serious problems, but that, in order to provide suitable entrance conditions and a proper direction of flow from the chute of Island 8 into the cutoff, extensive improvement dredging on the lower portion of Island 8 would be necessary before and during construction of the cutoff. Moreover, revetments and dikes in addition to those contemplated under the adopted program would be required, as well as extensive maintenance and reinforcement of existing structures due to channel adjustment above the cutoff during the development period. The principal benefit would be to navigation in the 13-mile reduction of the towing distance.

The fourth plan studied was the cutoff across Slough Landing Neck, or Bessie, extending from mile 900.1 to mile 873.9 (1937 mileage). After complete development of a cutoff at this location, the river would be shortened 20.9 miles. This alignment was found to be the most favorable from the standpoint of initial costs, minimum difficulties of channel adjustments, and maximum benefits to navigation and flood control. Soil borings furnished assurance that there would be little material of the type that would prevent uniform development of the cutoff channel after the pilot cut had been opened. The indications from the hydraulic model study were that the bar along the left bank above the cutoff would partially erode, and that the eroded material would pass through the cutoff channel. The bar to the right of the channel upstream from the cutoff would move into the abandoned channel and deposit in an area extending for about 3 miles downstream from the head of the cutoff. The location and direction of the downstream end of the cutoff would direct the current into Merriwether Bend, resulting in a minimum change in downstream alignment. The upstream portion of Merriwether Bend would provide a disposal area for material removed from the cutoff.

Construction of Bessie Cutoff would increase the water-surface slope through the cutoff and upstream from it. This slope change would increase maximum velocities at bankfull stage during the development stage. The velocity increase would be less at lower stages, and would be progressively less as the distance above the cutoff increased. After final development of the cutoff channel, and upstream from it, velocities would decrease, although it was thought that they would probably remain higher than under former conditions. Complete development of the cutoff would result in appreciable stage lowering upstream, but downstream from it, water-surface elevations would not be permanently affected. The stage reductions would substantially lower flood damages in the Birds Point-New Madrid Floodway under existing

conditions, and would reduce the cost of authorized modifications. However, these savings would be offset, in part, by the cost of levee setbacks that would probably be required due to increased bank caving caused by channel adjustments resulting from the cutoff. Construction of the cutoff would eliminate the need for some of the revetment remaining to be placed under the existing program, but adjustments in channel alignment and degradation resulting from the cutoff would require additional revetments and dikes, as well as reinforcement of some 43.9 miles of revetment. It was further believed that extraordinary maintenance of revetment and dikes would be required during construction and development of the cutoff and channel.

During the development period, navigation through and immediately above the cutoff would be difficult because of the high and unpredictable velocities that would be generated. However, it was concluded that after ultimate development of the channel (perhaps 2 to 7 years, depending on river stages experienced) navigation conditions in the reach from the cutoff to Cairo would not be materially different from those elsewhere in the Memphis District. Construction of the cutoff would separate New Madrid from the main channel, making necessary the maintenance of an entrance channel to the harbor. Stage lowerings would increase the maintenance dredging requirements in the harbor at Hickman, Kentucky. Construction of the cutoff would isolate 4,770 acres in Tennessee and 10,800 acres in Kentucky for an indeterminate period of time, until access to the area could be provided across the accretions in the upper bendway channel. In addition to tax losses for both States, the economy of Tiptonville would be affected by loss of about 15 percent of its trade area, which, of course, would be permanently lost to Tennessee, but would be replaced by gain in trade area to Missouri when access to the severed lands could be provided across the accretions in the upper bendway channel. If the cutoff were constructed, it would also be necessary to relocate the New Madrid sewer outfall, or to provide a treatment plant that would permit discharge of the effluent into the slack-water channel formed by the cutoff.

The cost of the initial and ultimate development of the Bessie Cutoff was estimated to be $61,932,000, of which only $126,000 would be non-Federal. Annual costs, based on a 50-year amortization period, were estimated to be $2,662,000, and annual benefits were $3,438,000, resulting in a benefit-cost ratio of 1.3. The benefits were $337,500 for prevention of flood damages and $3,100,000 for transportation savings. Construction of the cutoff would require 11 working seasons, with the cutoff scheduled to be opened during the third year. The first 2-1/2 years would be required for real estate acquisition and construction of the pilot channel.

The conclusions of the study were that it was feasible, from an engineering standpoint, to construct the Bessie Cutoff, and that it would shorten the river about 21 miles and improve its alignment. The cutoff would decrease the frequency of use of the Birds Point-New Madrid Floodway, but would not eliminate the need for it. Despite its advantages and the fact that a decision not to construct the cutoff would perpetuate the deepest and longest meander on the lower Mississippi River, it was concluded that the Bessie Cutoff should not be constructed because the majority of people who would be affected by it were unalterably opposed to it; the people in the town of New Madrid, Missouri, desired to remain on the river; severance of land would damage the economy of the area immediately to the east of the site; there was little support from navigation interests, even though some 90 percent of the benefits would accrue to navigation; and, finally, because orderly development of the cutoff would divert substantial sums from more important work of the Mississippi River and Tributaries Project. Accordingly, the Mississippi River Commission recommended that the proposed construction not be undertaken. The

Chief of Engineers concurred in this recommendation, subject to further consideration if a breakthrough should occur or appear to be unavoidable.

Channel Stabilization Investigations

In his history of the improvement of the lower Mississippi River, Colonel Elliott pointed out that experimental bank-protection operations were conducted as early as 1879. He described the various designs and procedures developed and tried through the year 1931, summarizing with the observation that the superiority of the continuous form of bank protection, that is, revetment, had been demonstrated, and that, to be successful in the lower river, revetment must be heavy, substantial, and impermeable. He noted development of the underwater survey, which revealed that the attack of the current upon subaqueous mattresses was much more severe than had been assumed previously, and predicted that the survey would point the way to material improvements in revetment design.

Study of meander phenomena

The increased urgency of achieving effective control of the alignment attained by construction of the 16 cutoffs in the period between 1932 and 1942 focused attention on the need for bettering revetment performance. Allotments for bank stabilization became a major item in the annual appropriations, thereby adding an incentive in the search for better revetment at lower cost. The levee system, designed to protect the Alluvial Valley from major floods, was rapidly approaching completion; therefore, control of river meander became the most urgent and difficult problem in the endeavor to preserve the safety of the valley from floods and to maintain the navigation channel. Two new lines of investigation were undertaken. One was the determination of the geology of the Alluvial Valley, for use in ascertaining from the sequence of geological events the various factors controlling present river forces. This study is discussed below under Geological Investigations. The other investigation was a laboratory research program at the Waterways Experiment Station on the meander phenomenon. In this model study by Captain J. F. Friedkin, authorized in 1942 and completed in 1944, small meandering streams were produced which caved their banks; built point and blanket bars; scoured in the bends and built up bars on the crossings during high stages; and filled in the bends and scoured through the crossing bars on low stages, behaving in every respect like full-size meandering streams. These small meandering streams reduced not only the dimensional and flow scales, but also the time scale, making it possible to observe in a few days the effects of what, in the prototype, would be many seasons of high and low stages. It was also possible to watch the movement of material transported by the stream from its point of origin in a caving bank to the point where it was deposited on a bar, and to observe the direction of top and bottom currents; the change in location of bank attack with change in stage; the relation of turbulence to bottom scour; and changes in river regimen at downstream points which result from changes occurring farther upstream. The effect of slope and volume of flow on meander pattern was also observed, and the relations between the character of materials forming the banks and the rate of meander were investigated.

These data might better have been obtained through study of the prototype if it were not for the fact that the Mississippi River is so large that it is impracticable to make hydrographic and bank surveys often enough in any section of considerable length to enable definite conclusions to be drawn therefrom on causes and effects of changes in river regimen.

From the results of the laboratory research work, the following conclusions were drawn:

a. In a stream having banks of little cohesion, the sands caved out of the banks are transported only a short distance downstream and are laid down on the first bar, where velocities are relatively low.

b. With the same discharge and slope, the most rapid bank caving and meander will occur with bank materials of the least cohesion.

c. With the same bank materials and discharge, the most rapid bank caving and meander will occur on the steepest slope.

d. With the same slope and discharge, a stream having cohesionless banks will develop wide and shallow cross sections which are hydraulically inefficient, whereas a stream with tough banks will develop relatively narrow and deep sections of greater hydraulic efficiency. The first stream will meander rapidly. The second will meander slowly and will be narrower and deeper than the first stream.

e. If the banks of a stream are composed of cohesionless materials, the prevention of bank caving by artificial means will cause the stream to modify its characteristics and to approach those of a stream flowing in tough material.

The conclusions furnished assurance that bank stabilization works, including dikes, properly located to retain good river alignment and in combination with dredging, can improve both a low water navigation channel and the flood-carrying capacity of the river. In addition, the studies indicated that the river will regain the length by which it has been shortened unless its shortened alignment is fixed by stabilization works. If it is allowed to regain its former length, the lowering of flood heights which has been obtained will be lost.

Revetment experimentation

Elliott has described the origination of the articulated concrete mattress, the development of different designs in the several Districts, and the eventual adoption of a standard mat design for use throughout the lower valley. Figure 15 depicts the details of the design presently used. Each section of this mattress is made up of 20 blocks, each 3 inches thick and 1 foot 2-3/8 inches by 3 feet 10-1/4 inches in area, held together by reinforcing fabric of corrosion resisting wire located in the central plane of the mattress section. A 5/8-inch by 3-foot 10-1/4-inch opening is left between the adjacent concrete blocks of each mattress section, and when the sections are assembled on the floating sinking plant preparatory to launching, an opening 1-3/4 inches wide by 24 feet 11 inches long is left between adjacent sections.

Willow mattresses had been employed in one form or another since 1878. However, the advantages of concrete, together with the increasing scarcity of willow growth and the defects inherent in that type of construction, resulted in a gradual decrease in willow construction and a corresponding increase in the amount of concrete mattress placed. Improvements in the articulated types ultimately led to the complete exclusion of all other types of subaqueous revetment in the main river. Soon after articulated concrete mattress was originated in the Vicksburg District in 1915, it became apparent that the leaching of bed materials through the mattress interstices was a possible cause of bank failure. In an effort to prevent this loss of material, numerous measures have been tried, such as placing a gravel blanket under the mattress, using a double layer of mattress, and filling the interstices with grout or asphalt. Although these expedients had some measure of success, they added to the required operations and, of course, to the cost. With the objectives of simplifying the operation and cutting costs, experiments were begun early in 1933, using a modified block design, termed the "V" type, which would reduce the opening between blocks and yet retain flexibility of the mattress as a whole. The name came from the fact that the longitudinal edges of the block were beveled rather than square; hence in cross section, two

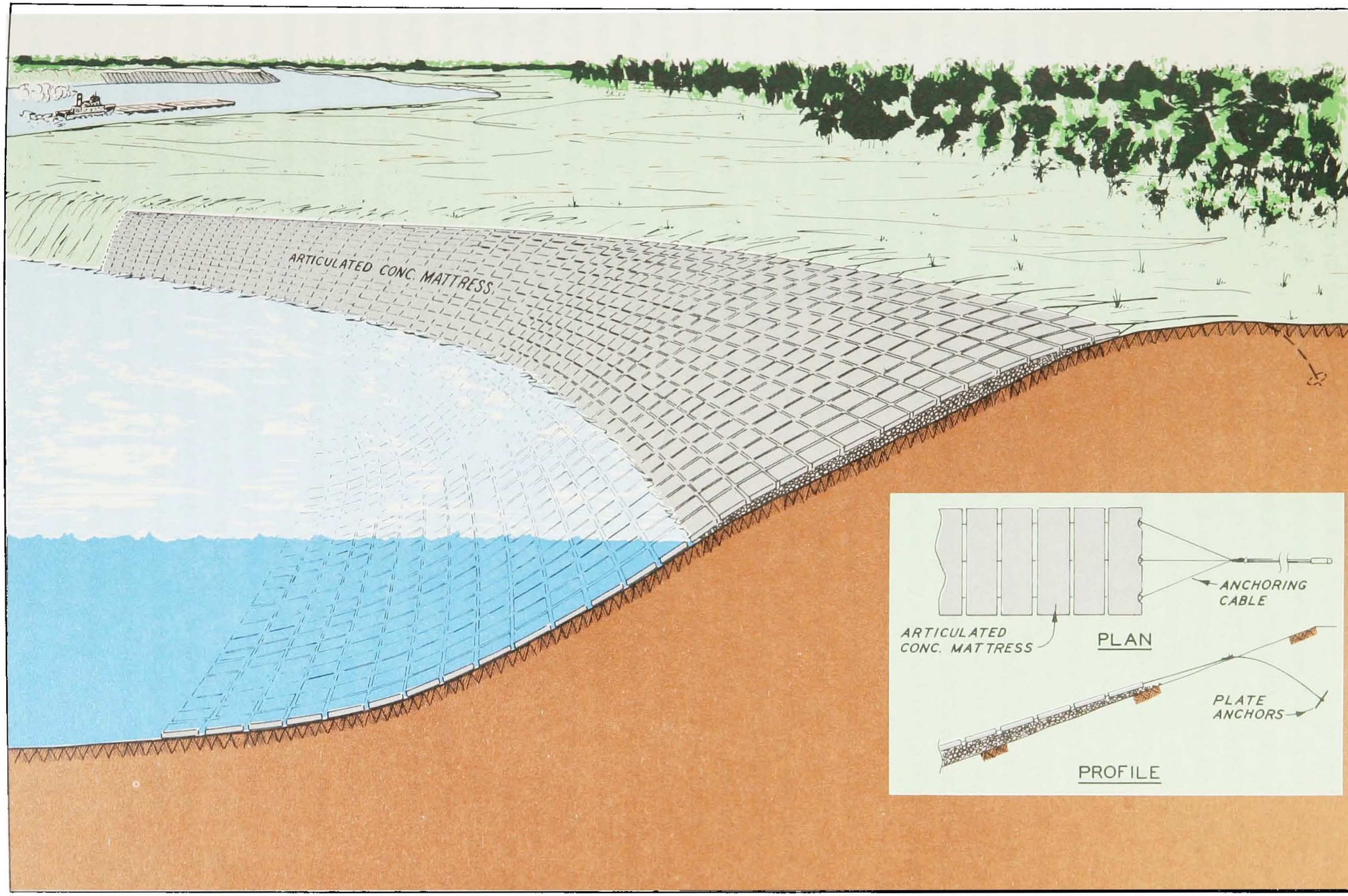


Figure 15. Articulated concrete mattress - standard details

abutting blocks formed a V at the joint. Five designs were tested. One had a single bevel from top to bottom of block, whereas the other four were designed with bevels of various pitches from both edges to the center, so that their cross sections each showed two V's, the bottom one being inverted. In the early experiments, forms for the bottom V made of wood, hollow cardboard, and collapsible metal strips were tried, and all were found to be unsatisfactory. In some instances, the V form stuck to the concrete and formed a wedge when the mattress was launched over the gunwale. This wedge broke the longitudinal wires. Efforts to find a more economical and labor-saving method of casting the articulated mattress led to a plan, in 1945, which utilized a divided steel form and a casting pallet. The lower part of the form was built into the pallet. The top part was removed after the concrete had taken its initial set. The mattress was removed in 7 days, using a vacuum-type lifter to remove the mattress from the forms. It was thought that use of the new technique, an adaptation of mechanized methods used in concrete highway construction, would facilitate casting operations, increase production, and substantially reduce costs.

Test operations conducted at Richardsons Landing in 1947 indicated that the V-type mattress could be satisfactorily cast by mechanized methods at a substantial cost saving over the standard type of mattress cast by hand-labor methods then in use. By 1951, it was believed that the mat could be cast and satisfactorily handled if vacuum lifters were used, but that further study would be required to eliminate the excessive breakage that occurred during sinking operations. On a production basis, the cost presumably would compare favorably with that of the regular mat, although the initial investment in forms and casting bases would be large. It was concluded that the performance of the V mat up to that time had been satisfactory, although the comparative effectiveness of the two types could not then be evaluated. In addition to reduction in area of openings in each square of mattress as a result of the V-type design, experiments were made on closure of the scarf-box openings, with an asphaltic rubber mastic. Difficulty in sinking the mat was increased due to the reduced openings. This circumstance and complications involving patents on the V-type mattress forms and on the vacuum-type of lifter led to abandonment of further efforts to develop them. The present standard mattress design has the longitudinal edges of blocks so beveled that, for interior blocks, the bottom opening is 5/8 inch in width and the top opening is 1 inch in width. No change has been made in the longitudinal openings between sections of a mattress.

Contemporaneously with the articulated concrete mattress experiments, investigations were conducted on uses of asphalt in mastic fillers to close interstices in the mattress and for underwater and upper-bank protection. Mastic fillers, using asphalt cement in combination with sponge rubber and Celotex, and in two commercial types of sewer-joint compounds, were tried. Application was made to the mat assembled on the deck of the sinking barge. The sponge rubber and Celotex fillers weathered excessively and became ineffective in about a year. The sewer-joint compounds made a better showing, but although they bonded well with the concrete, one of them became so hard as to cause rigidity of the mat which, of course, defeated the purpose of the articulation. Several mixtures were tried, composed of from 30 to 40 percent of asphalt; 59 to 69 percent of sand or loess; and 1 to 2 percent of excelsior, applied at a temperature of 350 F. to both the longitudinal and transverse openings of the mat as it was assembled on the deck of the sinking barge. The mastics containing loess were unsatisfactory, and only two of the test mixtures, using sand, were considered to be satisfactory, possibly because in those two instances the mastic had cooled to about 190 F. before the mat was launched. Additional tests using dried Spanish moss in lieu of excelsior were considered, but the admixture was not found to be satisfactory. This series of tests demonstrated that an effective mixture could be designed and applied at a satisfactory temperature, and that the small interstices of the mat could be filled at the casting field, thereby reducing the delay

to sinking operations by leaving only the larger longitudinal openings to be closed on the deck of the sinking barge. It was concluded that a device could be designed for satisfactory filling of the longitudinal openings in a short time, in order to cut down on delays at the time of launching. However, use of mastic fillers was not continued beyond the experimental stage because of excessive time-loss in applying the mastic and of difficulties experienced in sinking the mat, as was the case with the V-type mat.

Experimental mass underwater placement of hot sand-asphalt mixtures for prevention of scour of riverbanks was initially undertaken in 1946. The mixtures used contained from 10 to 16 percent, by weight, of 85-100 penetration asphalt cement (the amount depending upon the gradation of the sand aggregate), and mix temperatures ranged from 380 F. to 400 F. Placement was accomplished by bottom-dump barges capable of handling 150 tons of material in each of two 36- by 4-foot hoppers. About 20 inches of water stood in the bottom of the barges when empty, and, to avoid pouring the hot mixture into this water, about 20 to 40 tons of sand were first placed in each hopper. Dumps were usually spotted with the aid of a string-out of light pontoons, but, in some cases, a distance wire and sextant were used. The spacing between dumps was varied to provide coverage of 5 to 6 tons per square (100 square feet). The channel end of the revetment, where scour action had been severe, usually along the toe, was reinforced by double dumps. However, the initial underwater placements were made principally on existing mattresses for the purpose of reinforcing the toe to prevent scour from the outboard end as the channel deepened.

These early experiments with asphalt were general and random in nature because the process was new and untried. In order to develop more feasible and economical methods and procedures, a comprehensive program of experimentation was undertaken at the Waterways Experiment Station. The overall objective was to design an asphalt mixture which, when dropped in a mass underwater, would give the best coverage, considering spread; thickness; strength or resistance to disintegration; conformance to riverbed irregularities as the riverbed scoured; velocity of flow; depth of placement; and economy. Laboratory and simple small-scale tests were used to study possible improvement of the mixture. The more promising developments were explored further by means of field tests on as large scale as the Experiment Station facilities permitted. The final experiments were conducted in the river at full scale. Data collected during tests on sand-asphalt mixtures, supplemented by observations made during the test period, resulted in the conclusion that mass sand-asphalt mixtures for underwater protection of riverbanks should contain approximately 25 percent of asphalt cement. No type of asphalt other than asphalt cement was satisfactory. The asphalt cement should be of a penetration grade between 50 and 150, and the mix temperature at time of placement should be not less than 225 F., nor more than 275 F. No admixtures were found that would make mixtures less viscous. It was established that aggregates covering the range of gradations to be expected from Mississippi River sandbar materials are adequate for use in producing sand-asphalt mixtures. The experiments demonstrated that a sand-asphalt mixture can be dropped in a large mass through a considerable depth of water and develop a mat having satisfactory coverage, within certain limitations. However, the adequacy of sand-asphalt mixtures for underwater revetments could not be fully ascertained until large-scale placements covering a wider range of conditions were made and observed over a period of years. The experiments did not fully develop adequate procedures for constructing laminated dikes of successive layers of wet sand and asphalt, but small-scale tests showed little promise. Observation of the performance of a mass sand-asphalt dike indicated the practicability of the material for underwater groins if the mixture is placed on a firm foundation.

Another type of bank protection using asphalt was employed on the lower river in the period between 1934 and 1942. It consisted of a compacted reinforced asphalt mattress for the graded riverbank below

Figure 16. Launching reinforced asphalt mattress

the water surface (see figure 16). Most of this type of protection was located below Baton Rouge, where it was placed over old willow mattresses as insurance against bank failure. Compacted asphalt revetment possessed many features of an effective subaqueous mattress. It was continuous, impermeable, fairly flexible, and resistant to abrasion. However, the impermeability of this mattress rendered sinking impossible where stream velocities were swift and where updrafts were strong. In the relatively low water velocities of New Orleans Harbor, conditions were favorable and little difficulty was experienced. On the other hand, at Grand Bay, Plaquemine, and White Castle, all in Louisiana, where current velocities exceeded 3 miles per hour and depths were over 100 feet, efforts to sink it were unsuccessful. In those cases, the river was described as floating the mattress for a time much like a flag in a breeze, after which the mattress was torn up or folded over downstream. Although the specifications called for a flexibility superior to that required for highway pavements, the mattress did not withstand the flapping, bending, and folding that occurred in many locations. Low water inspections showed that the asphalt had broken out of the shore edge of many of the mats, leaving only the exposed reinforcing. Examination by divers of some of the underwater work indicated that a substantial amount of the mattress had torn or ripped along the launching cables. In some locations, there was lack of cohesion between the layers above and below the wire-mesh reinforcing. Elsewhere, the mattress had broken up and was not affording protection. The cost exceeded that of the articulated concrete mattress, due, in part, to the large amount of plant required for the asphalt mattress. Efforts to remedy the many difficulties and deficiencies of this type of protection were unsuccessful. Following unsuccessful attempts to place the mattress at Cracraft and Yellow Bend, in Arkansas, and at Miller Bend, in Mississippi, in depths of 30 to 60 feet, placements were discontinued in 1942.

In 1943, experiments were started on construction and placement of a roll-type mattress made of reinforced concrete slats and designed to be sufficiently flexible to be rolled up on a launching drum, then unrolled in direct contact with the underwater slope in its final position on the river bottom (see figure 17). The mattress was cast on pallets in sections 60 feet long and 24 feet wide. The sections were made up of slats 4 inches wide, 1-1/8 inches thick, and 24 feet long, reinforced by 2- by 4-inch corrosion-resisting wire mesh. In the casting position, the slats were separated by openings 1/8 inch wide

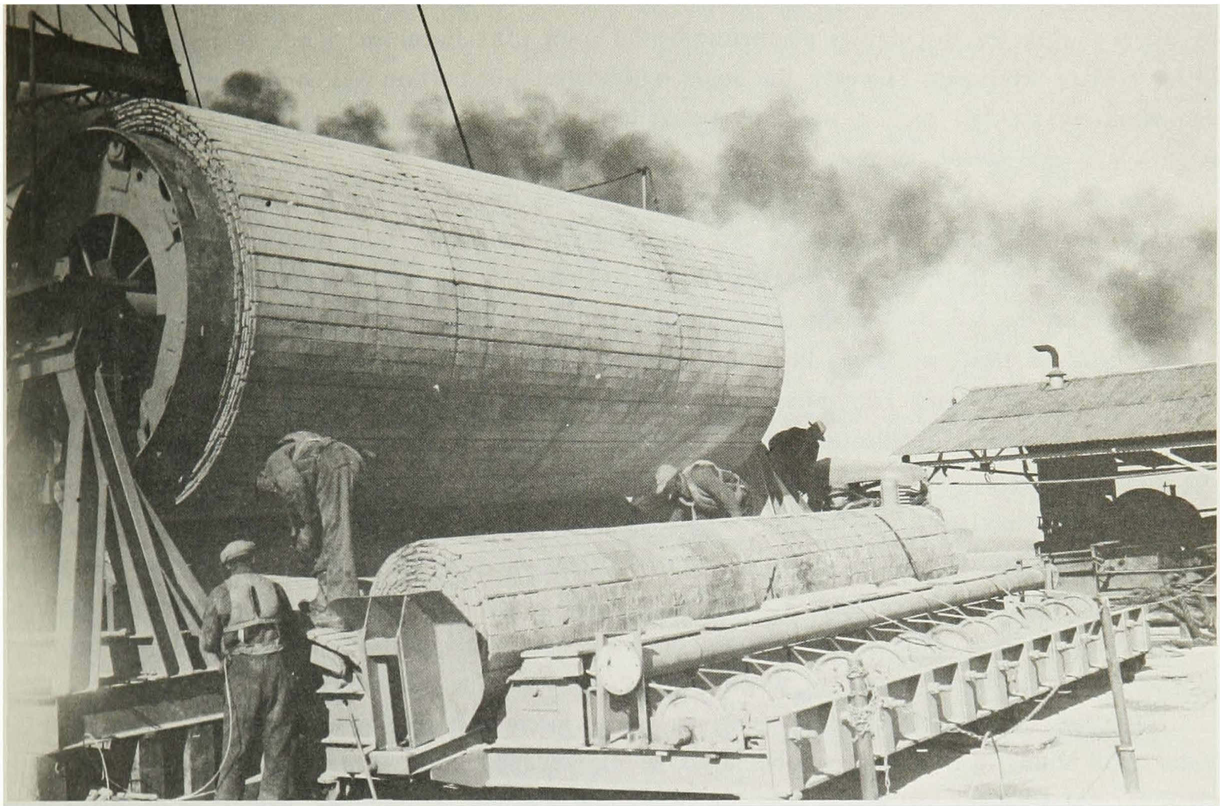


Figure 17. Roll-type mattress made of reinforced concrete slats

at the top and 1/2 inch wide at the bottom, but these measurements were reversed when the mat was inverted and placed on the underwater slope. After the concrete had cured for 2 days, the mat sections were rolled up on wooden cores 17 inches in diameter and strapped with steel packaging tape. Each 60-foot section formed a roll about 3 feet in diameter and weighed about 8-1/2 tons. After being transported to the construction site, each rolled mat section was rewound on a steel launching drum 8 feet in diameter and 26 feet long. It was thus possible to join several sections together to make up a mattress of the length required by site conditions. When this had been done, the launching drum was lowered into a U-shaped pontoon and placed in unrolling position below the string-out barges. The mat section was anchored ashore, and a spreader bar was fastened to the drum axle to facilitate unrolling the mattress into the river and retrieval of the empty drum. The launching drum was then released from the pontoon, allowing the mattress to unroll as the drum rolled along the underwater slope. The empty drum was drawn back to the shore, and the string-out moved 12 feet upstream. Thus, the roll-type revetment was laid in continuous strips 24 feet in width by any multiple of 60 feet in length, and with each successive strip overlapping the previous downstream mat by 12 feet to obtain double thickness.

Initial experiments with the roll-type mattress were conducted in New Orleans Harbor in 1943. In a preliminary test to develop the technique for rolling and unrolling, a mattress with wooden slats was used. The following year, concrete mats were prepared and used to revet 700 lineal feet of bank, with an extension 240 feet into the river to a depth of 40 feet below mean low water. During this installation, the need for modification of the launching procedure was apparent, but the effectiveness of the mat as a bank revetment could not be determined because a sandbar partially blanketed this

installation during the following high water season. In 1945, additional mattress sections were prepared for use at another test installation, planned to be the lower 1,000 lineal feet of a 5,000-lineal-foot extension of an existing revetment. However, the upper 4,000-lineal-foot portion was completed late in the season, and work on the test section was interrupted by high river stages. During the flood season, the test section was completely destroyed.

During 1945 and 1946, the roll-type mattress was placed on the left bank at the Miller Bend (Mississippi) revetment in extension and maintenance operations that included, also, placement of articulated concrete mattress and concrete blocks. In 1946, about 4,340 lineal feet of the roll-type mattress was placed on the left bank at Mounds, Mississippi. Also, about 1,900 lineal feet of this mattress was placed, early in 1946, at Lucas Bend, on the right bank of the Red River below Shreveport (outside the Mississippi River and Tributaries Project area), as an emergency measure to arrest a caving bank. Time did not permit mobilization of the proper launching equipment, so the mats were unrolled on the underwater slope with an improvised hook and roller device. The mats successfully arrested the bank recession until they were overtopped. A later survey showed that the mats were badly undermined, apparently due to insufficient width of the mattress and breaking during the improvised launching operation. Because of its condition, the revetment could not be relied on to furnish permanent protection, and deflection dikes were installed above and below it. This protection by the dikes prevented a determination of the adequacy of the revetment, by itself, in this location.

Although the flexible roll-type mattress was an interesting development that would be useful for some applications, it was not considered to be rugged enough to furnish the type of service that is given by the standard articulated concrete revetment mattress. Accordingly, placement of this type of mattress was discontinued in 1947.

Requirements for increased amounts of upper bank paving, following passage of the 1944 authorization of the Cairo to Baton Rouge stabilization project, led to development of uncompacted asphalt pavement for the upper bank (see figure 18). The material was hot-mixed in a barge-mounted

Figure 18. Uncompacted hot asphalt paving on upper bank

plant, transported in barges, dumped into a spreader box on the prepared bank, and spread to grade without subsequent compaction. In 1945, a laboratory study, at the Waterways Experiment Station, of mixtures for this purpose concluded that those using either coarse or fine river bar sand appeared sufficiently permeable when asphalt cement contents ranged up to 8 percent. Other tests were conducted to determine trends of effects of several variables on the relative flexibility and permeability of various mixtures, but the conclusions were general and suggested that some determinations could better be made in the field. Later tests showed that, as the asphalt binder aged, it became harder and more brittle, leading in turn to an increase in rate of surface wear. Moreover, the pores of the uncompacted pavement soon were clogged by silt carried by ground water at low river stages, and by deposition during high river stages. This condition reduced the permeability enough to cause the same type of failure as that which occurred with compacted asphalt pavement and monolithic concrete pavement. The addition of weep holes and French drains was not effective.

Riprap upper-bank paving, consisting of a course of broken stone with an average thickness of 10 inches, has been used almost exclusively on the tributaries and on the Mississippi River above Memphis. A study of comparative maintenance costs made by the Memphis District showed that between 1949 and 1960 the annual maintenance cost for uncompacted asphalt pavement was $0.51 per square (100 square feet), whereas that for riprap was $0.15. In view of the estimated 20-year life expectancy for uncompacted asphalt paving, it was concluded that riprap paving could be economically justified, even if its cost exceeded by 2-1/2 times that of the uncompacted paving. This finding led to abandonment of asphalt upper-bank paving in the Memphis District in 1960.

During high water in 1951, New Orleans District forces laid a short section of revetment on a levee spur at Grand Bay near New Roads, Louisiana, composed of precast blocks of hot-mixed sand asphalt. Figure 19 depicts the casting procedure. The casting barge was moored close to the upper bank

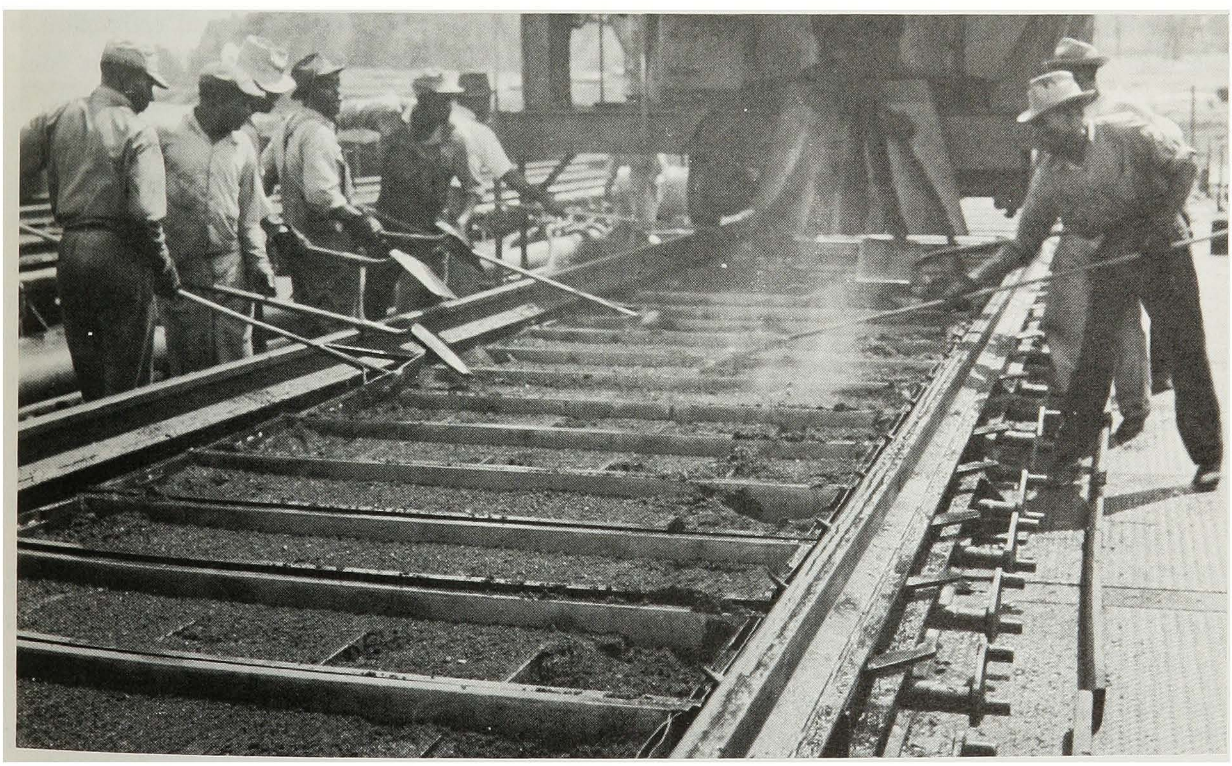


Figure 19. Asphalt block casting plant

so that the blocks would be exposed during low water stages. Examination at a low stage showed that the blocks had merged and provided complete coverage of the bank. Additional projects were then set up to investigate further the merits of this type of underwater paving. One project was at Algiers Point in New Orleans Harbor, where the Mississippi River makes a sharp turn, subjecting the point to severe erosion by river currents. The Algiers project consisted of a downstream extension of the existing Algiers Point revetment. The extension began near the Canal Street ferry landing and continued 2,290 feet downstream to the lower side of the Third District ferry landing. The block mat started about 55 feet from the water's edge, which is as close to the wharves as a casting barge could be moored, and extended into the river from 250 to 500 feet, depending upon the configuration of the underwater bank. The water depth varied from 35 feet near the bank to 90 to 150 feet in midstream. Another test section, 1,000 feet in length, was constructed at Morganza. The entire revetment at Port Allen, 3,220 feet in length, was constructed of asphalt blocks in 1954.

The blocks, 20 by 16 by 5.5 inches, were cast in pans on a barge, using asphalt from a floating mixing plant. The hot mix was leveled in the pans by hand, and was not rolled or compacted. After each section of pans was filled with hot mix, water was allowed to flow into the pans until the mix was well covered. After about 30 minutes of cooling, the pans were turned over manually, allowing the asphalt blocks to fall into the river.

Asphalt blocks were used for ordinary revetment repairs in the vicinity of New Orleans from the time of the initial experiments in 1951 until December 1959, when this type of repair was discontinued due to the slow pace of the operation and the excessive amount of labor required. The necessity of making several passes of the block machine to insure adequate coverage led to excessive cost.

The cost of fabric amounts to about one-third of the total cost of materials for articulated concrete mattress and fittings. Attempts have been made to find a less costly material. However, the fabric wire must not only withstand the stress of rough handling, but must resist corrosion after prolonged exposure to Mississippi River waters and soils, debris of all kinds, atmospheric conditions, and embedment in concrete; and it must not be impaired by subjection to slight abrasions. Galvanized steel wire fabric was used from the time of introduction of articulated concrete mattress in the Vicksburg District in 1916 until 1931. Experimentation with a copper-clad wire began in 1931, culminating in the development of a molecularly welded copper-coated wire by the Copperweld Steel Company. A stainless steel wire, containing 18 percent chromium and 8 percent nickel, passed acceptability tests in 1937, but the cost was not competitive with the copper-clad wire. Numerous other experiments to develop a less costly fabric included aluminum coated wire, aluminum alloys, plastic-coated steel, glass fibers, and various steel alloys. A copper-plated wire, manufactured by two separate plating and drawing processes in reverse spiral plating vats and designated "Copperply," has been found to be acceptable. As of 1970, specifications for the wire from which mattress fabric is manufactured prescribe Copperweld, Copperply, or Type AISI 301 stainless steel wire, which are the only types of wire so far tested that meet performance requirements. Of these three acceptable types of wire, Copperweld has usually been supplied because it is available at lowest cost.

The feasibility of reducing the size of fabric wire has also received attention. As a result of a 1962 study, the diameter has been reduced from 0.182 to 0.162 inch. This change without sacrifice of strength or other physical requirements produced a savings of about $1,250,000 in the first contract. This savings was equivalent to 25 percent of the cost under the former specification requirement.

Other investigations since 1952 have been directed at development of a less costly method of assembling the articulated concrete mattress. Some of these are continuing in 1972. A research and

development contract to develop a mechanical connector to replace the twist wires was negotiated in 1961. The contract proposal included assembly of 20 hydraulically activated fastening heads on each of two carriages. The carriages were to be suspended from a truss located above the inshore edge of the assembly barge and from the gantry rails on the outshore edge. The proposed connector was to be a loose coil wire seizing formed around the fabric wires and launching strand. The scheme was abandoned because the machines could not be installed without major modification of the sinking plant, and because no satisfactory coil-forming die having a satisfactory life could be devised.

In 1965, another contract was made for development of improved mat-handling cranes and an air-powered tool capable of making a new friction tie for fastening the mattress together and to the launching cable. The friction tie would make possible the elimination of the "U" bolts now used to prevent the mat sections from sliding down the launching cables as the mat is sunk and would reduce the amount of hand labor required. By 1967, a tool that would make a satisfactory tie had been developed and new cranes installed. Tying devices are presently in operation in the Memphis and Vicksburg Districts.

Geological Investigations

Fisk's geological investigations of the Alluvial Valley

As previously noted, there was, in the early 1940's, a growing realization of the need to control river meander, and this prompted two new lines of investigation—a laboratory research program, conducted at the Waterways Experiment Station (briefly explained in the foregoing section) on the meander phenomenon, and determination of the geology of the valley for use in ascertaining, from the sequence of geological events, the various factors controlling previous river activities. The cutoff program was nearing completion, and river stabilization was obviously the next big problem to be faced. It was believed that broad geological information concerning the valley, giving an overall picture of the characteristics of riverbed and banks and furnishing knowledge of the river's performance in recent geological times, would be helpful in studying the complex phenomenon of river meander, but no such information was available. Prior to 1927, there were not even available accurate maps of the entire valley area. By 1941, topographic maps of the Alluvial Valley had been prepared by the Mississippi River Commission, and planimetric maps of the deltaic plain had been issued by the State of Louisiana. Aerial photographs had been made for mapping purposes and in connection with the crop-control program of the Department of Agriculture, making possible the study of scaled photographs. Supplementing the scattered borings made in the valley prior to 1927, there were the logs of deep borings made for engineering projects along the river, for water supplies, and for petroleum exploration—more than 16,000 in all.

Through the cooperation of Louisiana State University and its Department of Geology, Dr. Harold N. Fisk was engaged to study the nature and origin of the lower Mississippi River Alluvial Valley, and to determine the sequence of events in valley evolution. His study, which was begun in 1941 and concluded in 1944, also undertook to establish stages in the development of the river system and to differentiate the major factors leading to establishing the river in its present-day course and controlling its present behavior. Figure 20 exemplifies one of the results of the study.

Traces of former occupancy by the Mississippi River and its tributary systems appearing on the surface of the lower Alluvial Valley were studied by means of aerial photographs, topographic maps, and field examination. From these studies, the history of the flood plain surface was reconstructed and

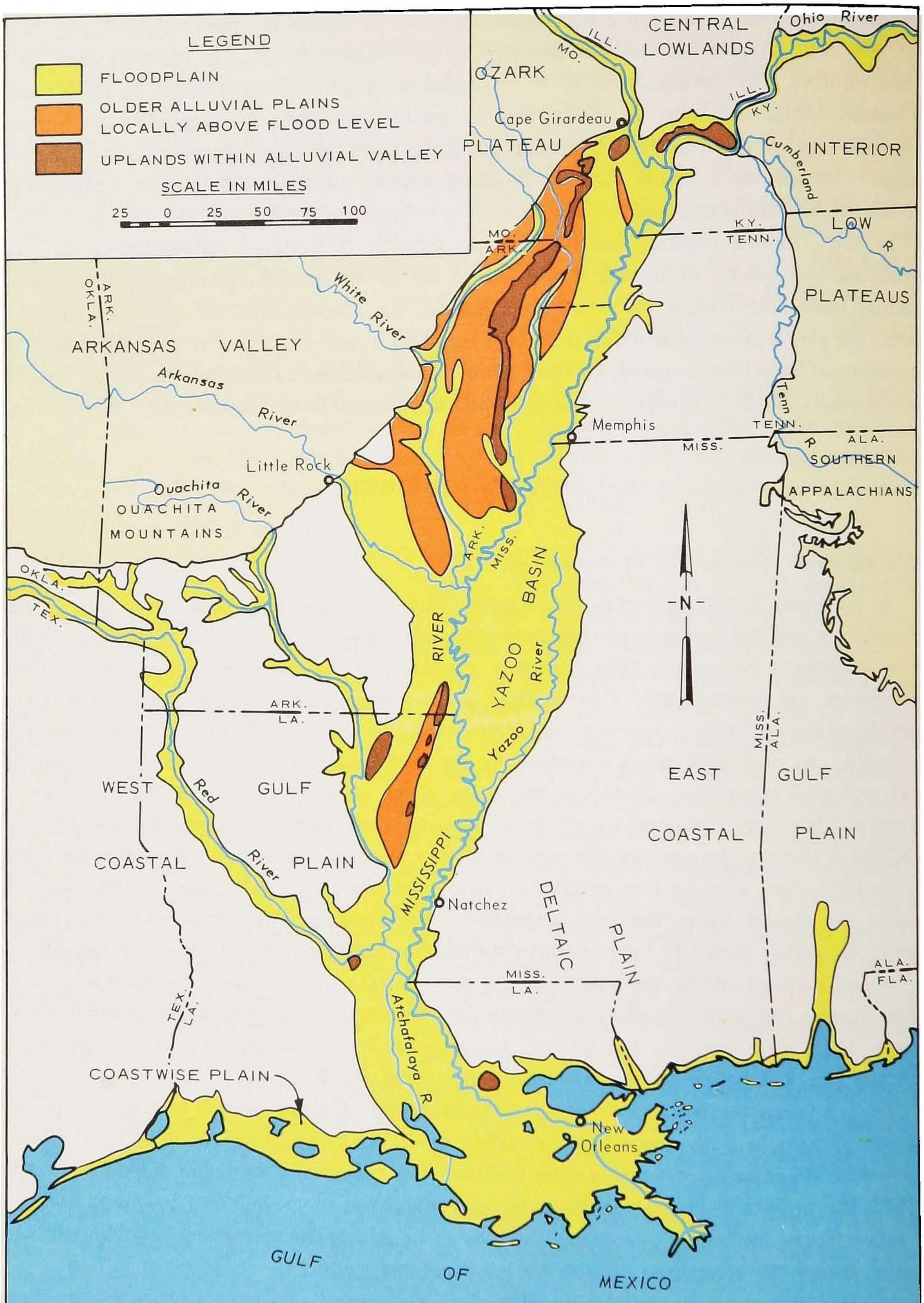


Figure 20. Physiographic map - Central Gulf Coastal Plain

integrated with other studies of the nature and distribution of subsurface strata. Thousands of well logs were examined. From these detailed surface and subsurface studies were derived conclusions concerning the development of the Mississippi River and the lower Alluvial Valley. Figure 21 illustrates one of the cross sections developed from these studies.

The studies showed that the Mississippi River came into existence in early Pleistocene time as a result of drainage changes brought about by partial burial of the continent under an ice sheet. Waters were diverted southward into the Central Gulf Coastal Plain and occupied preexisting valleys determined by the structure of the region. Several oscillations in sea level associated with waxing and waning of the ice sheets, formed during subsequent glacial stages, caused alternating entrenchment of the stream system followed by filling of the entrenched valleys. The present Alluvial Valley is underlaid by thick alluvial deposits laid down in a deeply incised valley system during the waning of the last ice sheet. Alluviation has continued since sea level reached a stand. Filling of the entrenched valley with Recent alluvium was accomplished largely by the formation of low alluvial fans near the mouths of the tributary stream valleys. Remnants of these fans in the north end of the valley rise above normal flood level, for example, Sikeston Ridge. Many drainage changes accompanied the construction of the fans and eventually led to establishment of the present Mississippi River.

The Mississippi River is termed a "poised" stream; that is, it has shown no tendency either to aggrade or degrade its channel. It is flowing on the lowest valley slope which it has attained throughout the history of the lower Alluvial Valley. Its characteristics are determined by its discharge, valley slope, and type of alluvium through which it flows. It inherited its present low slope from the Ohio River, which it joined at the end of the valley near Cairo, Illinois, after abandoning a course to the west of Crowleys Ridge. It also acquired its large discharge in the north end of the valley when it established the Ohio River junction. The character of the alluvium through which the Mississippi River flows was determined by a long and complicated history of stream velocity activity within the valley.

The Fisk studies developed that the present Mississippi River is truly the end product of the evolution of Mississippi Valley drainage. For the first time in the history of the river, the relations of discharge, valley slope, and materials comprising the bank and bed of the stream are such that a good low water channel is maintained throughout the entire length of the valley. As such, it has reached, and is maintaining, a better channel for flood control and navigation than at any previous stage in evolution of the system.

The information and conclusions in the Fisk report were of great value in the engineering of the flood control and navigation project. The outstanding contributions of immediate applicability were the mapping of the courses that the river has followed in its present meander belt, estimated to have taken place over a period of about 2,000 years; the location of clay deposits in old courses which are near the river or have been cut by it; and the conclusions concerning the poised character of the river and the phenomenon of meander.

In 1944, Dr. Fisk undertook a supplementary geological study of fine-grained alluvial deposits in the Mississippi Alluvial Valley, investigating the effect of such deposits on channel migration; bank caving; growth and development of meander loops; and similar features. The position of the deposits was mapped from aerial photographs and examinations on the ground, followed by checking of the mapped areas by means of borings. Also utilized were the boring logs acquired for the earlier study. Next, information concerning the physical properties and other distinguishing features of the different types of fine-grained deposits was compiled. Finally, the effects of these materials on river regimen were studied.

The report of this study, published in 1947, noted that the most important factors controlling the activity of the Mississippi River are valley slope, load, discharge, and the nature of the bed and

bank materials through which the river flows. The influence exerted by each of these factors can be readily interpreted from the changes which the river has undergone during the period of Alluvial Valley aggradation and from the characteristics of the present river in different sections of the valley, as described in the earlier report. The poised nature of the stream shows that both valley slope and discharge (with its normal periodic stage fluctuation) have been nearly constant factors since sea level reached its stand. It also indicates that load is a constant factor when the entire river is considered, but local variations are known to have a bearing on local stream action. With other factors constant, the nature of bed and bank materials constitutes the most important factor affecting present stream activity. Bed and bank materials regulate channel migration through their control of bank caving, amount of locally derived bedload, and local changes in river alignment.

The nature of bed and bank materials is very important in any consideration of the many interrelated factors controlling river activity. Fine-grained bed and bank materials form cohesive, slightly permeable beds which effectively slow down the rate of bank recession, and which are capable of standing with deeper subaqueous slopes than sandy material. Bank stabilization is accompanied by local deepening and narrowing of the channel cross section and by a change in stream velocities. It also exerts a control over local river alignment and thereby serves to direct downstream bank attack. In controlling alignment, the relatively stable deposits may become the indirect cause of bank instability downstream if they direct river attack into easily erosible deposits.

The report found, further, that the rate of channel migration and the width and depth of the river can be correlated to the thickness of fine-grained sediments forming the bed and bank. Fine-grained deposits cave into the river by a process termed "slumping," which involves slippage of bank segments into the river caused by scouring action in the channel thalweg at the toe of the bank. Scouring removes a portion of the bed of the river, and, if sands are present, there is a tendency for them to move toward the point of scouring. The movement, which occurs because the pore pressure in the saturated sands is higher than the water pressure in the river, or because the slopes are too steep, is directed toward the point of least pressure; that is, where scouring is taking place. The transfer of sands weakens the foundation, and the overlying cohesive materials collapse into the river. In the southern part of the valley, where the top stratum of fine-grained deposits extends to or below the depth of channel scouring, it is difficult for the river to remove sufficient materials to cause slumping. In these areas, migration is slow and the channel is deep and narrow. On the other hand, in the northern part of the valley, where the top stratum is comparatively thin, bank caving in areas of fine-grained deposits is almost continuous; migration is consequently rapid; and the channel is relatively wide and shallow.

In conclusion, the report found that local fine-grained deposits in the bank line have played an important role in growth and migration of Mississippi River meander loops and formation of reaches. By locally hindering migration of the meander loop arms and by controlling local stream alignment, these resistant bank deposits have altered the shape of the loops and have been directly responsible for their being cut off from the river. Reaches (nearly straight stretches of the river) are considered to be the end product of river migration in a meander belt because they are confined between "clay plugs" filling the arms of meander loops. As a result of long-continued river activity, the channel fillings are so distributed that river migration is restricted, and no meander loops can be developed.

Fisk's studies of Atchafalaya Basin and problem of Mississippi River diversion

In 1950, the Chief of Engineers called for a study to be made of the Atchafalaya and Old Rivers as a basis for future planning. His directive required a review of all available engineering information

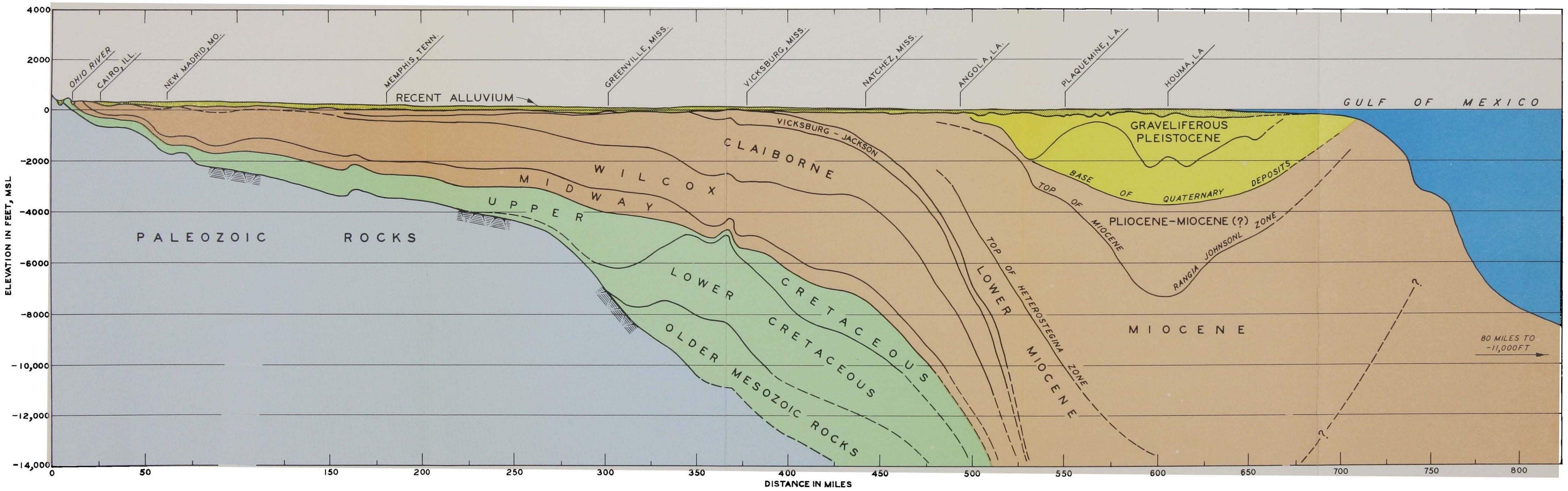


Figure 21. North-south cross section - Central Gulf Coastal Plain

on changes in the carrying capacity and alignment of the rivers, to be complemented by a study of the geology of the basin and its probable effect on the rivers' future regimen. Dr. Fisk was engaged to report on all the ascertainable geological facts.

Earlier, in a letter dated 9 July 1945, addressed to the President, Mississippi River Commission, Dr. Fisk had replied to a request for an opinion whether, from the viewpoint of the geologist, the continuing increase in flow of the Atchafalaya River was an indication that capture of the Mississippi River by the Atchafalaya was a possibility. He said that, based upon a study of the geological history of the several diversions of the Mississippi River which have occurred in Recent geological time and upon a study of the development of the Atchafalaya River, he felt that there was a definite possibility that the Mississippi River would be captured by the Atchafalaya. He added that he could not predict when capture might take place without more data at his disposal.

Time did not permit complete study of all the considerations planned for the Fisk report and, accordingly, an interim report was made early in 1951. This report concluded that geological studies up to that time supported the view that the Atchafalaya would continue to enlarge until it captured the Mississippi. It expressed the opinion that there was no sign of a diminishing rate of channel enlargement, and recommended that, if corrective measures were planned, they be undertaken as soon as possible. It stated that measures involving direct control of Mississippi River discharge were preferable to partial measures.

Issuance of the interim report did not halt the full geological study, which was not completed until 1952. The investigation utilized, as appropriate, the data from the earlier Alluvial Valley studies. The basic approach was to search for the factors causing past Mississippi diversions and to use them to appraise the diversion potential of the Atchafalaya River. Data for the earlier studies were supplemented by aerial photographs which were used to reconstruct the geological history of the basin and to delineate its physiographic features. An additional 200 borings were made for this study. Researches were made of published and unpublished reports and documents to locate information on the general geologic background, the historic and cultural development of the Atchafalaya region, and the diversions of other rivers. Early maps, graphs, and charts were also examined for evidences of changes in Atchafalaya bank lines and channel cross sections, and for growth of the Atchafalaya delta. Studies were made of the effects of dredging, levee building, railroad and highway construction, and other cultural developments. Suspended and bedload samples were taken at selected stations along the Mississippi above and below Old River, as well as in the channels of the Red, Atchafalaya, and Mississippi, to determine the distribution of sediment load at the present point of diversion and downstream from it. In order to predict the rate and method by which the Atchafalaya River would advance its delta following establishment of a single channel, studies were made of the type, source, and thickness of the deltaic deposits which would aid in estimating the rate of the lengthening of the Atchafalaya River and the time of ultimate establishment of a single channel to the sea. The coastal marsh and bay bottom deposits south of the basin, which will eventually form the bed and banks of the Atchafalaya, were investigated to ascertain their effect on the enlargement of the Atchafalaya.

Also included in this comprehensive examination were the distributary channels of the modern Mississippi and ancient Lafourche-Mississippi and Teche-Mississippi Deltas for the purpose of reconstructing the processes by which these deltas were built. Past Mississippi diversions were critically examined to determine the factors influencing their occurrence. The most recent diversion of the Mississippi, which brought about the abandonment of the Lafourche course below Donaldsonville, was examined to ascertain the history of this latest change in Mississippi River flow.

This study resulted in the conclusion that the Atchafalaya was following a pattern characteristic of former Mississippi River diversions, each of which captured the entire flow of the master stream within an estimated period of 100 years. No natural processes were known which might prevent further enlargement and eventual diversion of the entire Mississippi River flow. The study concluded, further, that the Atchafalaya was then (1952) in its intermediate stage of diversion. At that time, approximately 25 percent of the water of the Mississippi was being diverted, and indications were that a critical stage could be expected at some time before 50 percent of the flow was diverted. After this stage had been reached, closure of the Mississippi below Old River would be rapid and diversion would be relatively uncontrollable. It was further estimated that the critical stage would occur on or before the time of 40 percent diversion. Analysis of trends led to the conclusion that the diversion would reach a critical stage between 1965 and 1975. The diversionary process would be accelerated by frequent floods or sustained high water flows through the distributary; by continued dredging in the lower Atchafalaya Basin; and by the occurrence of a critical stage of development before the time of 40 percent diversion. Finally, the report noted that any sudden increase in deterioration of the Mississippi channel immediately below the point of diversion should be interpreted as marking the beginning of the critical stage.

Subsequent and continuing geological investigations

The initial geological studies made under the supervision of Dr. Fisk or in consultation with him included the mapping of ancient stream courses occurring in a strip 20 to 30 miles wide along the Mississippi River and utilized aerial photographs and field examinations to map the position of fine-grained alluvial deposits. However, these investigations did not provide complete coverage of the Alluvial Valley; many gaps remained within the strip along the river, and large areas outside the valley were not covered. Recognizing the value to engineering planning of adequate geological information, and foreseeing increases in the number of project works in unmapped areas, the Mississippi River Commission arranged for the Waterways Experiment Station to map the geology of principal tributaries and to make special geological studies to aid in the solution of engineering problems. A number of these studies have been completed and the results have been published. Others are in progress.

In 1950, the Waterways Experiment Station completed and published as Technical Memorandum (TM) No. 3-319 a study of the geology of the lower Red River. This report describes the geologic history of the Red River Valley downstream from the Arkansas-Louisiana boundary, and shows its relation to existing physical features; outlines the configuration of the bedrock underlying the alluvium; lists prominent depositional environments and resulting characteristic soils; and comments on the engineering significance of some of the deposits.

Again, in 1951, a report on the geology of the lower Arkansas River Alluvial Valley, from Pine Bluff, Arkansas, to the mouth, was published as WES TM No. 3-332. The study summarizes the geologic history of the lower Arkansas, and describes soil types and environmental conditions for point-bar, channel-filling, natural-levee, and back-swamp deposits.

In 1958, WES published a technical report, TR No. 3-483, on the geology of the Mississippi River deltaic plain in southeastern Louisiana, in which the major depositional environments of the deltaic plain from Atchafalaya Bay to Chandeleur Islands south of the approximate latitude of the north side of Lake Pontchartrain are mapped and described. The report includes a summary of the engineering properties of the deposits. Most of the mapping is to a scale of about 6.75 miles to the inch.

WES TR No. 3-601, published in 1962, entitled *Distribution of Soils Bordering the Mississippi River from Donaldsonville to Head of Passes,* comprises soil maps by depositional types in a series of plates

to a scale of 1 inch to the mile for a narrow strip along about 189 miles of the Mississippi River. The accompanying text outlines the geologic history, describes the distribution and the physical and engineering characteristics of the sediments, and discusses the effects of these sediments and other factors on river migration.

Comprehensive mapping of the Yazoo Basin in a series of 15-minute quadrangles to a scale of about 1 inch to the mile was accomplished in 1956. The maps and descriptive geologic data were published as WES TR No. 3-480, and revised in 1968. All or parts of 42 quadrangles lie within this basin, which extends from Vicksburg to Memphis, and which is about 200 miles long and 65 miles in maximum width. The areal distribution of the alluvium by depositional environment and contours on top of the Tertiary bedrock are superimposed in color on standard quadrangles previously printed in black and white with cultural and topographic features. One or more geologic sections through lines of boreholes are provided for each quadrangle map. The text accompanying the maps incorporates a discussion of the geologic history, a listing of the types of alluvial deposits with their methods of deposition and the soil groups characteristic of each, and a columnar section of the underlying Tertiary strata. Engineering soil maps prepared during the investigation have been furnished, as the quadrangles were completed, for use in planning flood control structures in the Yazoo Basin.

Similarly, a program of geologic mapping in the St. Francis Basin was begun in 1963 and is expected to be completed in 1974. Data on the distribution of the alluvial deposits are superimposed in color on standard 15-minute quadrangles as they are obtained. Five of the 46 quadrangles involved are not properly a part of the St. Francis Basin, but have been included with the basin maps for convenience to show the geology of the adjoining New Madrid to Cairo area. Priority is given to those portions of the area bordering the Mississippi River, for use in the Mississippi River Levee Safety Study currently in progress. Besides maps and sections, the report (WES TR No. 3-659) includes a text with descriptions of the geologic settings for the deposition of the alluvial-surface deposits and a listing of top-stratum deposits, with illustrations by diagrams and aerial photographs; descriptions of occurrence; methods of deposition; and their characteristics. Geologic mapping of the Boeuf-Tensas Basin was started in 1966 and is nearing completion. Maps, sections, and descriptive data will be published as WES TR No. 3-757. The report will include all or parts of thirty-one 15-minute quadrangles, 26 of which have already been mapped. A similar report covering portions of 13 quadrangles in the Ouachita Basin between Sicily Island and Camden, Arkansas, was published as WES TR S-69-2 in 1969. This mapping was done in 1967 and 1968. The mapping of 10 quadrangles along the Mississippi River from Artonish to Donaldsonville, Louisiana, in 1967 and 1968 (published as WES TR S-69-4 in 1969) completed coverage of soil distribution along both sides of the main stem from Cairo, Illinois, to Head of Passes. These maps will likewise be useful for the Mississippi River Levee Safety Study and for planning of future project works.

Even in 1972, large portions of the lower Mississippi Alluvial Valley areas are densely wooded and traversed by few roads or trails. Aerial photography is an efficient and economical tool in mapping the distribution of soils in such areas. It enabled Dr. Fisk to obtain essential data in preparing his 1944 report. Since that time, photographic procedures, as well as interpretive techniques, have been improved. In addition, there are now available the logs of some 500,000 subsurface explorations, compared with the less than 20,000 that were on hand at the time of Dr. Fisk's report. These factors make it possible for soil distribution to be mapped in good detail and with relative accuracy. Knowledge of the depositional environment and its boundaries is required to permit interpolation into areas between boreholes, requiring use of both aerial photographs and boring logs for accurate construction of a soil-distribution map.

In mapping the distribution of soils in the lower Mississippi Alluvial Valley, there are recognized

seven depositional environments: natural levee, alluvial apron, point bar, back swamp, abandoned channel, abandoned course, and braided-relict alluvial fan.

The term "natural levees" describes low ridges which border both sides of streams that frequently overflow their banks and form the levees by deposition of soils from suspension as the floodwaters leave the main channel and lose velocity. The deposition is greatest, consequently the levee is highest, adjacent to the stream because the decrease in velocity is greatest as the water overtops the banks. Natural levees in the lower valley may be 15 feet or more in height. The soils making up these deposits are well graded from sand to fat clay, with the clay predominating. The grain size decreases in a landward direction, and from upstream to downstream.

Alluvial aprons are deposits of material washed onto the flood plain from adjacent highlands; consequently, they occur at the base of valley walls or as upland remnants within the valley. The texture of the soils contained in these deposits depends upon the type of material forming the upland source of a particular deposit and the distance it has been transported. Material is finer around the perimeter of the individual fans that make up the apron.

Point-bar deposits form on the insides of river bends as the stream migrates. They cover large areas in the lower Mississippi Alluvial Valley. Two types of materials make up the point-bar deposit—the elongated curving ridges, or bars, of sand and silt formed during high stages, and the silty and clayey materials which accumulate in the intervening swales or depressions between the sand ridges during falling or low stages. The deposits are about 30 feet thick, but much greater thicknesses are not uncommon.

Back-swamp deposits are fine-grained soils, mainly clays, laid down in shallow-ponded floodwaters landward from the natural levees. These deposits also cover large areas in the flood plain of the Alluvial Valley and generally increase in size and thickness southward to about the latitude of Baton Rouge, where they intermingle with deposits of deltaic environment. Their thicknesses often exceed 100 feet.

Abandoned channels are meanders, or portions of meanders, abandoned or cut off by the river when shortening its course. The sediments accumulating in the abandoned channels are usually clays or fine silts. Thicknesses of these clay plugs ranging from 100 to 180 feet are not considered unusual.

Abandoned courses are lengthy portions of the river left for a new route through the flood plain. Such features may be many miles in length, and are often occupied by smaller streams. The basal deposits in these old courses are usually sandy, but clays and silts eventually complete filling of the channel. These clays are not as thick as similar deposits in abandoned channels.

Braided-relict alluvial fan deposits consist of sediments laid down by rapidly shifting aggrading streams during the earlier stages of valley alluviation, and are often intermixed with alluvial sands of tributary streams from bordering uplands. The braided-stream deposits were formed by the Ohio and Mississippi Rivers. Interfingering lenses are normal in these deposits. Thicknesses range from a few feet in the northern part of the valley to as much as 40 feet in the southern part. Soils range from sand to clay.

The sediments in the deltaic plain of southern Louisiana are grouped under five categories: the prodelta, intradelta, interdistributary, marsh, and swamp deposits. The term "prodelta deposits" describes the first sediments to be laid down in a depositional area by a stream building an advancing delta. These fine-grained sediments may be widely distributed by wind, marine, and fluvial currents. Accumulations of prodelta clay 400 to 500 feet thick, broken only by a few thin lenses of sand or silty clay, have been found in southern Louisiana. Intradelta deposits are the coarser textured sediments (sands and silts) which are associated with delta advance. They are deposited as bars or submerged fans at or just seaward from the mouth of the distributary. Interdistributary deposits are made up of sediments laid down between the distributaries of deltas by water spilling over low natural levees along the

distributaries. These deposits are almost entirely soft clay. Marshes are flat areas at or very close to water level, covered with vegetation consisting mostly of grasses and sedges. Organic matter forms an important part of marsh deposits. The amount of inorganic deposition depends upon the proximity of sources of sediment, either marine or fluviatile. Swamps are distinguished from marshes by the presence of a dense growth of trees. The deposition is usually highly organic, such as that found in marshes.

A study, which is, in a sense, complementary to geologic mapping, was started in 1955 of the radio-carbon dating of samples of wood, peat, or shell fragments collected from subsurface borings. Radioactive carbon 14, found in all living things, either plant or animal, begins to disintegrate at the death of the organism. By measuring the residual radioactivity of carbon 14 in parts of plants or animals preserved in sediments, the date of deposition (assumed to be the same as the date of death of the organism) can be ascertained with relative accuracy. Although such dating is possible only for sediments less than 30,000 years old, the approximate life of carbon 14, it has proved very useful in dating many of the events recorded in the geological framework of the lower Mississippi Alluvial Valley established by Fisk. Accurate dating of sediments filling ancient meanders and abandoned river courses provides a reliable basis for estimating long-term rates of Mississippi River migration, sedimentation, delta growth, and other related matters.

Additional studies and reports have been made by the Waterways Experiment Station since 1942 on localized problem areas and specific structure sites. The report of such studies, in most instances, includes a detailed geologic map of the immediate vicinity showing types and distribution of the alluvial deposits present. In addition, a study entitled *Groundwater in Alluvium of Lower Mississippi Valley* was made and published in 1964 as TR 3-658 by the Waterways Experiment Station. This report contains data on the alluvial aquifer of the valley from Cape Girardeau, Missouri, to Port Gibson, Mississippi, and discusses factors that produce changes in it. Engineering aspects, such as water quality, corrosion, dewatering excavation areas, effects on canals and levees, and clogging of wells, are also discussed. Maps of the Tertiary bedrock surface and the piezometric surface are included.

In 1964, there was initiated an investigation of the geological influences affecting bank erosion at selected revetment sites along the lower Mississippi River, designed to show the effects of thick and thin top-stratum materials on the mechanics of bank failure, and to discuss the part of the clay plug in retarding bank erosion. The report of this investigation may show that the soil-distribution maps can be useful in predicting reaches of future bank failures and active bank erosion.

Finally, studies of fine-grained alluvial deposits, using X-ray photography, have been completed. The use of the X-ray makes possible the study of cryptostructural and depositional features not otherwise visible, and changes in such features occurring under superimposed loads. The purpose of these studies is to investigate the effect of the cryptostructure on the physical properties of the clays.

The geologic mapping programs make available maps that are valuable aids to the engineer whether engaged in planning, design, or construction. They are of definite assistance in selecting tentative construction sites, in making more accurate initial cost estimates, and in earlier recognition of design and construction problems. Subsurface explorations are, of course, necessary to verify anticipated conditions and to obtain samples for laboratory testing, but they may be much less extensive and more costly than would be possible without the advance information from the maps. Wells and berms to control underseepage can be planned from the maps because they show the distribution of both the deposits responsible for the seepage and the deposits which restrict it. Similarly, the maps furnish information to aid in designing dewatering systems and in locating water wells. The maps also facilitate

reconnaissances for borrow materials and for gravel aggregates. Haul-road routes and sites for mixing plants and maintenance shops can be determined from the soil information available on these maps.

Project Flood and Design Flood Flow Line Studies

A fundamental determination in planning a flood control project is the magnitude of flood for which provision is to be made. Prior to the 1928 act, the highest flood stages of record, increased by allowances for freeboard and the effect of confinement by levees, constituted the basis for levee grades. The flood used in the design of the Jadwin Plan was that calculated by the Weather Bureau to be the "maximum possible" and by the Mississippi River Commission to be the "maximum probable." The stages computed by the two agencies were essentially the same, but where there was a difference, the higher stage was used. This resulted in a project flood at Cairo with a stage, if confined, of 66 feet–a discharge of 2,250,000 to 2,400,000 c.f.s. The Weather Bureau derived its flood by using the maximum Ohio River flood with "the Mississippi, Cumberland, and Tennessee Rivers contributing their tides at just the proper time to insure the greatest effect at Cairo, an improbable occurrence it is admitted but nevertheless a remotely possible one." With the proposed Birds Point-New Madrid Floodway passing an estimated 550,000 c.f.s., the computed design flow line at Cairo was established at 59.0 feet. The computed stage of 74.5 feet at Arkansas City (estimated flow, if confined, 2,850,000 c.f.s.) resulted from the flow at Cairo increased by maximum computed flows in the Arkansas and White. Below the Red, this flood, increased by flow from the Yazoo and Red but decreased due to river-channel-reservoir capacity, gave the project flood, which was calculated to be 3,000,000 c.f.s. Below the mouth of Old River, half of this flow would be carried by the Atchafalaya River and floodways.

Following the major flood of 1937, meteorological studies indicated that a flood with peak flow of 2,600,000 c.f.s. might occur. In a report dated 6 April 1937, which was contained in Committee Print, Committee on Flood Control, House of Representatives, Committee Document No. 1, 75th Congress, 1st session, the Chief of Engineers stated that provision should be made for protection against a flood which, without reservoir control, would reach 2,600,000 c.f.s. in the Mississippi between Cairo and the Arkansas. The Chief of Engineers, in that report, recommended a comprehensive system of reservoirs on the tributaries of the Mississippi River; additional protection of lands in the vicinity of Cairo; and related work, all based on a flood having a peak discharge at Cairo of 2,600,000 c.f.s. These plans received congressional approval upon passage of the 1938 act authorizing the construction of rivers and harbors and flood control works. Frequency studies had shown that a peak discharge at Cairo of 2,600,000 c.f.s. has the same probability of occurrence as a peak discharge of 3,000,000 c.f.s. at Arkansas City with the White River backwater protection levee crevassed. For the purposes of the 1941 review report, printed in House Document 359, 77th Congress, 1st session, and because of the unusual pattern of the 1937 flood, a confined flow of 3,065,000 c.f.s. with the White backwater levee crevassed was assumed for Arkansas City. The figure of 3,000,000 c.f.s. at the latitude of Old River was not modified. Although consideration had been given in earlier studies to the possible effect of upstream reservoirs, the 1941 revision was the first instance in which an allowance was made for them. A reduction of 150,000 c.f.s. in the design flow was made between Cairo and the mouth of the Arkansas River, making the project design flood at Cairo equal to 2,450,000 c.f.s.

A review of the project flood was again undertaken in 1954 to determine if changes should be made in the light of new techniques that had been developed and in consideration of additional basic data amassed. A great economic development taking place in the protected area made it imperative that the adequacy of the design flood be assured. Because of the relatively short period of hydrological records for so large a drainage area as the 1,246,000 square miles above Red River Landing, it was assumed that all possible critical combinations of storms and runoff events had not been observed. The study

developed a number of hypothetical combinations and practical transpositions of storms of record to establish flood magnitudes that could reasonably be expected to occur and produce major floods. It included the determination of flood hydrographs, under natural conditions and as regulated by planned operation of existing and prospective or near-future (EN) reservoirs in all lower Mississippi River tributary basins. These hydrographs were analyzed to ascertain the influence of seasonal variations of storm probability over the tributary basins, and to select a project design flood.

A complete report of the study is reproduced as Annex C, Project Design Flood Study, to the Comprehensive Review Report of 1959 (House Document 308, 88th Congress, 2d session). It noted that storms that produce floods on the lower Mississippi occur chiefly during the months of January through April, and to a lesser extent in May and June. Forty-four of the largest storms were selected for further study in the development of hypothetical floods. The storms selected did not necessarily represent the largest of record, but were chosen because of the floods they produced on the lower Mississippi River and their adaptability for meteorological analysis. They included those of March 1913, June 1928, January 1937, and January 1950 over the Ohio River Basin; February 1938 and May 1943 over the Southwest and Middle West; and April 1927 and June 1947 over the upper Mississippi and Missouri River Basins. The study also included 35 sequences illustrative of winter, early spring, and late spring storms, and variations in contribution by the several tributary basins due to seasonal variations in the probability of occurrence of large storms and heavy runoff. Some of the storms were transposed; others were used in their actual positions over tributary basins with orientation, sequence, intensity of rainfall, and runoff factors so modified as to produce the maximum runoff in the Mississippi River. Four of these hypothetical sequences were selected for final study. They were identified as Hypo-Floods 52A, 56, 58A, and 63.

Hypo-Flood 58A was found to produce the maximum unregulated discharge at all key stations below the Ohio River. This sequence represents a winter flood, with the maximum contribution from the Ohio River, and is typical of floods produced by the storm pattern most likely to cause critical floodflows below Cairo. Discharges of Hypo-Flood 58A, modified by existing reservoirs and those programmed to be built by 1970 assumed to be completed and in operation in accordance with the approved schedule for modified flows, were considered to be the best estimate of the largest flood in the lower Mississippi River for which protection should be provided, and it was accordingly selected as the project design flood. Figure 22 is a diagrammatic representation of that flood. The following tabulation affords a comparison at key points of the project flood revised in 1956 with the design flood of 1941 and the greatest discharges of record:

	Peak Discharge in 1,000 c.f.s.			
Location	*Maximum Flood*	*1941 Project Flood*	*1956 Project Flood**	*1956 Project Plan***
Cairo, Illinois	2,002	2,450	2,850	2,360
Memphis, Tennessee	2,020	2,450	2,770	2,410
Helena, Arkansas	2,041	2,450	2,710	2,460
Arkansas City, Arkansas	2,615†	3,065	3,210	2,890
Vicksburg, Mississippi	2,340†	2,761	2,960	2,710
Natchez, Mississippi	2,350†	2,800	2,970	2,720
Latitude of Red River Landing, Louisiana	2,345†	3,000	3,320	3,030

* Unmodified by reservoirs.
** Modified by existing reservoirs and those programmed to be built by 1970.
† Estimated confined discharge.

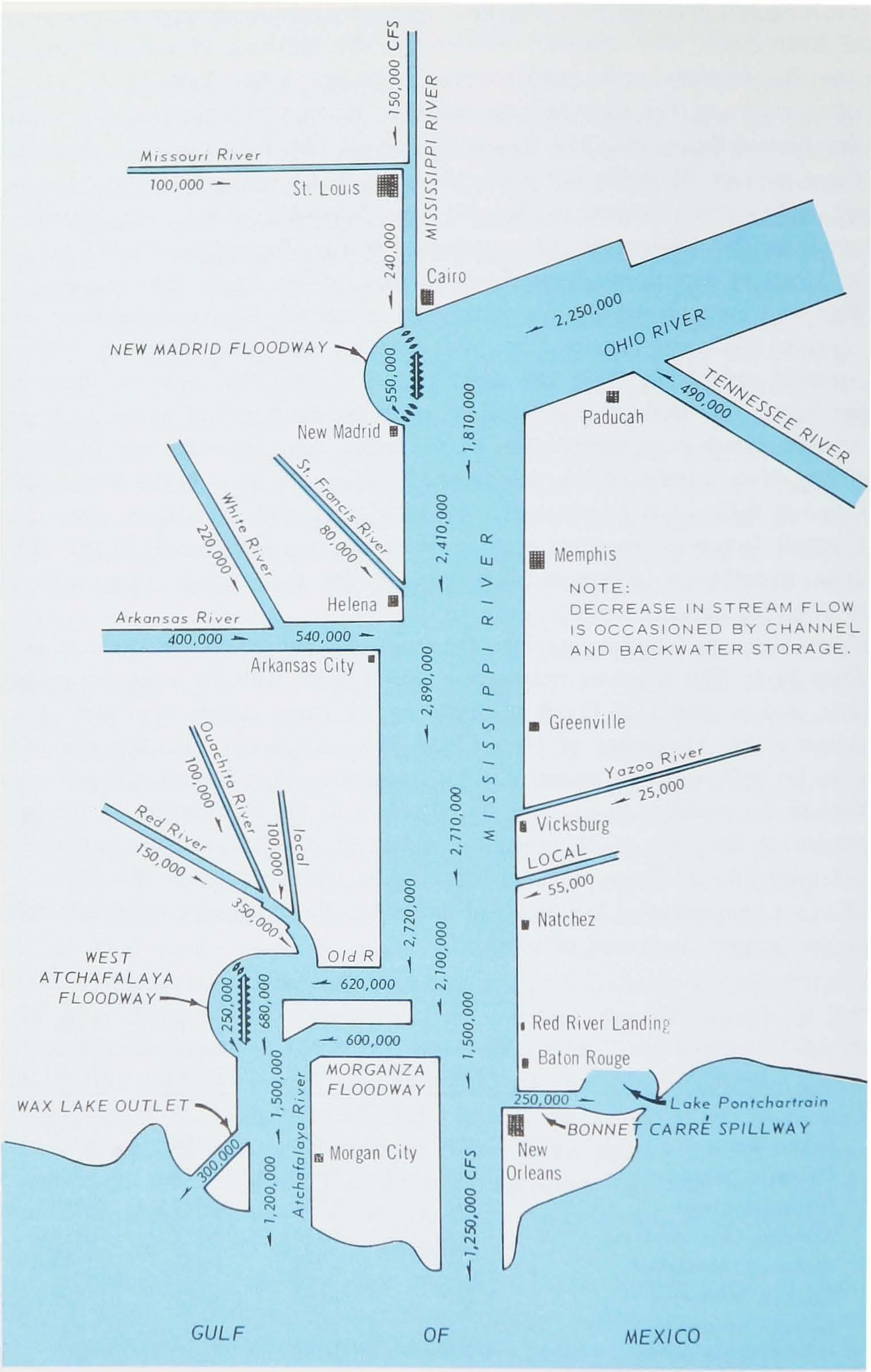


Figure 22. Project design flood

Adoption of the new project design flood made it necessary to recompute the flood flow line throughout the length of the Alluvial Valley (see figure 23). The capacity of the leveed channel varies from year to year; consequently, the lower Mississippi, as with all alluvial streams, does not maintain a constant stage-discharge relationship. Changes may be temporary, because of movement of beds and banks, or permanent, because of major changes in course or manmade works of improvement. The cutoff program of the 1930's and other improvements have shortened the reach of channel between Cairo, Illinois, and Angola, Louisiana, and the channel alignment and cross section have been improved and stabilized to a considerable extent by revetments and dikes. Velocity increases due to steepened slopes and the general improvement by stabilization have raised the channel-carrying capacity at all stages throughout most of this reach. In some localities, the increase in capacity resulting from the cutoffs has been offset by retention in the main channel of flows formerly planned to pass down the Boeuf and Eudora Floodways. Stage reductions due to cutoffs are shown in figure 24. Substantial portions of the existing levees had several feet of freeboard over the stage of the design flood under improved channel conditions.

In computing the revised flow line, it was assumed that flows in the channel of the main stem were confined by the existing levees; that existing and authorized fuseplugs and control works in floodways and in existing and planned backwater levees would function as planned; and that the Old River control structures were in operation. Except for the middle reach of the main stem, the revised flow line was based on 1950 channel conditions because the 1950 flood was the most recent one large enough to represent flow conditions for a large flood, and also because hydrographic surveys of the river made in 1949 and 1950 were available. In the middle reach, 1945 channel conditions were used because, in this reach, the 1950 flood had insufficient overbank depths to represent flow conditions for large floods. A comparison of the revised flow line of 1956 with the project flow lines adopted in 1928 and 1941 is tabulated below:

	1928 Flow Line		*1941 Flow Line*		*1956 Flow Line*	
Gaging Station	*Elevation feet m.s.l.*	*Stage feet*	*Elevation feet m.s.l.*	*Stage feet*	*Elevation feet m.s.l.*	*Stage feet*
Commerce, Missouri	341.0	39.2	343.4	41.6	344.6	42.8
Cairo, Illinois	329.6	59.0	333.2	62.6	333.2	62.6
Memphis, Tennessee	237.3	53.4	238.7	54.8	236.5	52.6
Helena, Arkansas	207.3	65.4	205.3	63.4	204.3	62.4
Vicksburg, Mississippi, Bridge	104.8	58.6	106.0	59.8	104.4	58.2
Natchez, Mississippi	77.3	60.0	82.3	65.0	80.0	62.7
Red River Landing, Louisiana	63.0	59.5	63.0	59.5	61.0	57.5
New Orleans, Louisiana	19.9	20.0	19.9	20.0	19.9	20.0

Freeboard, the vertical height of a levee or other structure above the estimated maximum flow line of the levee design flood, is an allowance made to compensate for unavoidable lack of precision in flow line calculations and to prevent overtopping by waves. It usually includes allowances for stage fluctuations caused by wind tides, wave action, or surges which are of short duration, as well as an allowance for increased protection where unusual hazards exist. Current practice is to include an allowance

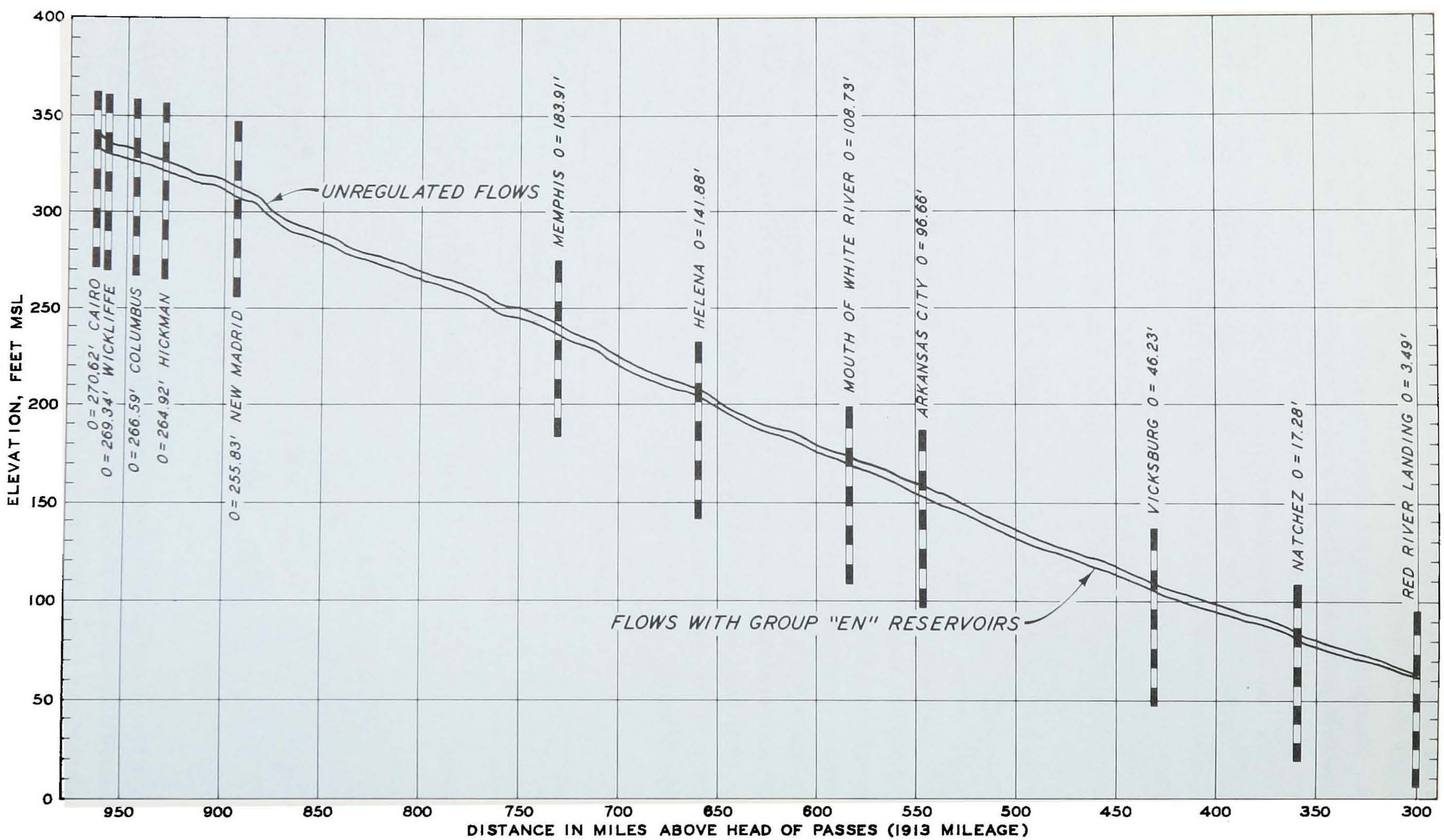


Figure 23. Profile of Mississippi River project design flood

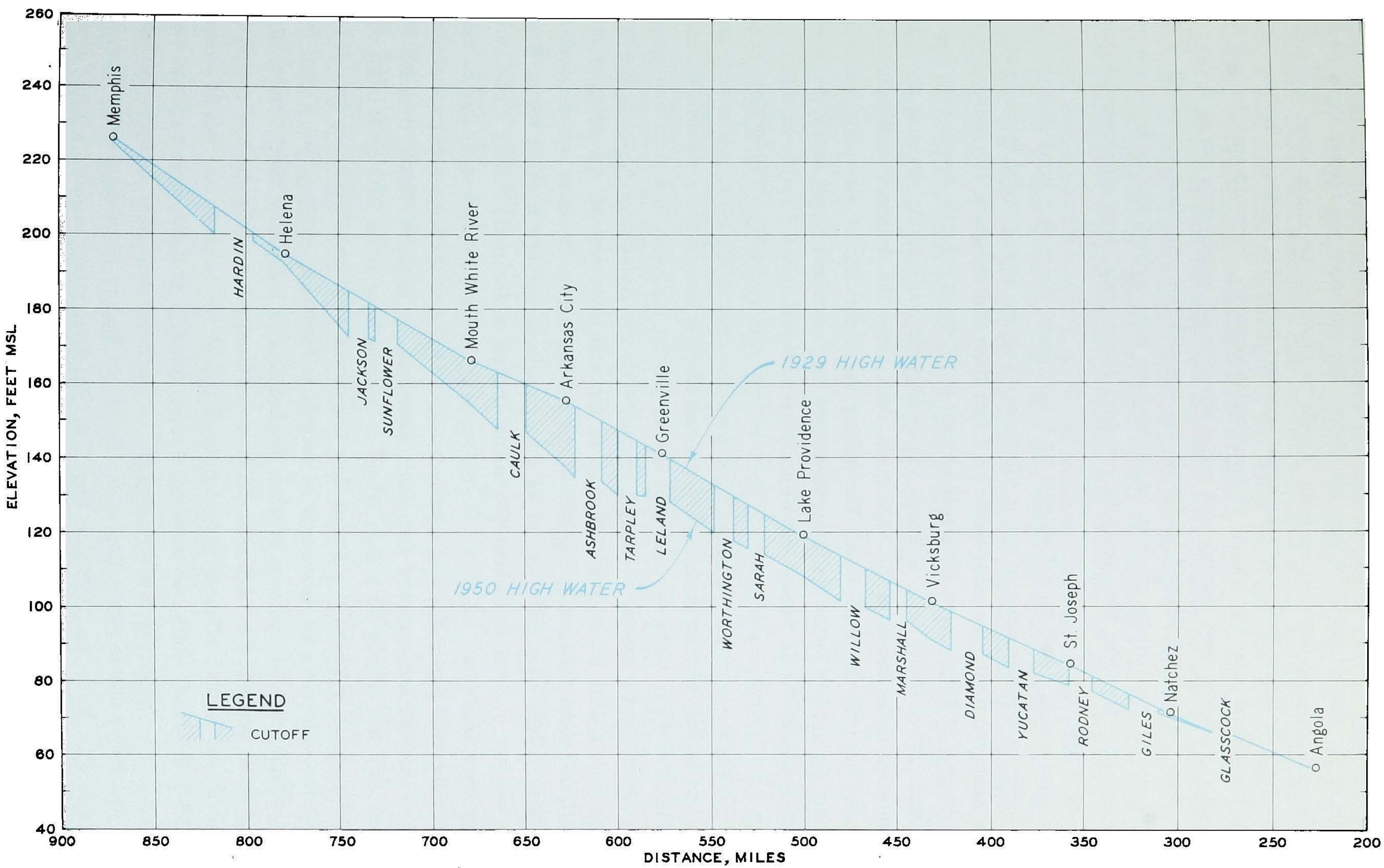


Figure 24. Stage reductions due to cutoffs

for changes in channel capacity that may occur between floods. Records of major gaging stations show numerous variations of as much as 2 feet in flood heights, and some appreciably more. In consideration of these records at the time of the 1954 flow line review, the conclusion was reached that a freeboard of 3 feet is the minimum amount that normally should be provided. Locations where foundation or other conditions preclude raising the levee to the height necessary to provide the desired freeboard demand deviation from the general rule. For reasons of construction economy, freeboard must be held to the minimum amounts consistent with security and reasonable cost of maintenance during floods.

To compensate for varying degrees of foundation consolidation and shrinkage of fill, a liberal allowance of excess fill was initially made in establishing the gross construction grade for the project levees. In consequence, the levee lines generally remained above grade, even after consolidation and shrinkage had occurred.

The 1928 project plan called for a freeboard of 1 foot above the project flood flow line, except the main-line levees at the lower end of major tributaries along the areas flooded by backwater from the Mississippi, where the front levee grade would be 2 feet lower than elsewhere. This provided generally for an increased height of 3 feet above the grades adopted in 1914 except for the fuseplug and backwater levees, which were left relatively low. Although the 1928 grade south of the Arkansas was modified in 1931, it continued to be known as the 1928 grade. Also, above the Arkansas, revisions in the 1928 grade were made following the 1937 flood. Recognizing the importance of preventing breaks in the main levees along the upper parts of the highly developed St. Francis and Yazoo Basins, the backwater levees near the mouths of the St. Francis and White Rivers were maintained 2 feet lower than the main levees opposite them. Likewise, the main-river levee at the lower end of the Tensas Basin along the area flooded by backwater from the Mississippi River was maintained at the 1914 grade so as to overtop during great floods, thereby relieving pressure upon the main levee for some distance upstream and utilizing the storage in the Red River backwater area, and also to prevent too much flow from continuing into the main river below Angola instead of finding an outlet via the Atchafalaya River or floodways.

The cutoff and channel improvement program in the main river between the Arkansas and the Red greatly increased the flood-carrying capacity of the channel and the floodway, which consequently reduced the height of the crest flow lines of all floods confined between frontline levees. However, this reduction was not uniform throughout the middle section of the river, making a wide variation in the resulting levee freeboards. In 1941, calculations and a hydraulic model study showed that the crest flow line of the 1927 project flood, if reproduced, would be below the project net grade of frontline levees between Yancopin, Arkansas, and Deer Park, Louisiana, by amounts ranging from less than 1 foot to as much as 8 feet, except for a short length of fuseplug levee at the 1914 grade in the vicinity of Vaucluse, Arkansas, at which point the crest flow line of the 1927 flood would top the 1914 grade by about 1-1/2 feet. However, the advantages of such large freeboards existing over a great part of the river were nullified by the existence of lesser freeboards at a few places, which thus constituted the controlling grade. Bringing the freeboards closer to uniformity by raising the low stretches to a common standard gave a more efficient and economical use of the levees in the middle section. As a result, the 1941 flow line, which was based on a larger discharge at Cairo, greater channel capacity due to the cutoff and channel-improvement program, and increased main-stem discharges between the Arkansas and Red Rivers due to elimination of the Boeuf and Eudora Floodways, ranges from several feet above to somewhat below the 1928 flow line. The 1941 levee grades provided a 1-foot freeboard over the design flood, except that the Cairo levees had a 2-foot freeboard, and the east-bank levee along the Yazoo Basin was given a 3-foot freeboard.

The 1956 flow line, which, as has been noted, is based upon still larger flows modified by more extensive reservoir control, varies from nearly the same as that of 1941 to about 4 feet below it. This is due largely to an improved channel capacity resulting from further channel improvement and stabilization. Thus, levees previously built to the prescribed grade of 1 foot above the 1928 and 1941 flow lines have freeboards of more than 3 feet above the 1956 flow line for the greater portion of their length. This circumstance made it feasible to adopt a 3-foot freeboard which, with a single exception, was applied equally to both the east- and west-bank levee systems irrespective of previously authorized differentials in grade. The exception was the Tiptonville-Obion River left-bank levee, which, when completed, will extend from high ground above Tiptonville, Tennessee, to near the mouth of the Middle Fork of Forked Deer River. About 31.5 miles of the upper part of this levee has been completed to a net grade 2 feet below the 1941 flow line in accordance with its authorization. The 1956 gradeline for this levee is 1 foot below the 1956 flow line. Since the 1956 flow line is lower than the flow line of 1941, this levee will provide an increased degree of protection of the area without endangering the west-bank levee.

The following tabulation affords a comparison of the three historic levee grades on the main stem between Cairo and New Orleans, expressed in feet of stage:

	1928 Grade		*1941 Grade*		*1956 Grade*
Location of Gage	*East Bank*	*West Bank*	*East Bank*	*West Bank*	*Both Banks*
Cairo, Illinois	60.0	60.0	64.6	64.6	64.6
New Madrid, Missouri		52.5		53.7	54.7
Cottonwood Point, Missouri		49.5		49.8	48.7
Memphis, Tennessee		54.5		55.8	56.6
Helena, Arkansas		66.5	67.0	66.5	65.6
Arkansas City, Arkansas		63.5		66.0*	62.1**
Lake Providence, Louisiana		57.5	59.3	57.2	57.5
Vicksburg, Mississippi					
Canal Gage		61.0	66.0	64.0	63.5
Bridge Gage				60.8	61.2
Natchez, Mississippi		61.0		66.0	65.7
Red River Landing, Louisiana		60.5		60.5	60.5
Baton Rouge, Louisiana	50.0	50.0	50.0	50.0	48.8
Carrollton, Louisiana	25.2	25.2	25.2	25.2	25.2

* At new location 62.8.
** At new location 60.4.

Levee Design Studies

New Orleans was the site of the earliest levees built on the lower Mississippi for flood protection. Records tell of a levee built between 1717 and 1726, located above and below the site of what is now Jackson Square. The high water mark was about 3 feet above the banks, therefore the levee was constructed to a height of only about 4 feet, with side slopes of 1 on 2. This levee, with a crown width of 18 feet, was designed to be a rampart, public landing, and walk, which accounted for the

cross-sectional area that was then considered to be greatly in excess of requirements for restraint of floodwaters. Measurements of a number of levees on the lower river by Humphreys and Abbot in 1851 showed mean dimensions for the west and east banks (Baton Rouge to Carrollton), respectively, of 4.7 and 4.0 feet for the top width; 14.6 and 10.5 feet for the bottom width; 4.7 and 4.3 feet for the height; and 1.4 and 1.0 feet for freeboard above the 1851 high water. The disastrous flood of 1858 swept away miles of such weak levees.

As early as 1728, administrators in Louisiana for the French crown held each settler responsible for building levees for protection of his own lands. The individual planter determined the size and type of his levee without regard to uniformity of dimensions or specifications. This assignment of responsibility to the riparian owner was carried over into the first comprehensive levee and road law enacted by the new State of Louisiana in 1816. Flood control legislation in Louisiana, Mississippi, and Arkansas before the Civil War incorporated suggestions on how to locate and build levees. A prominent State engineer expressed the opinion that, to be effective, the levees must constantly be increased in size. By the time the Mississippi River Commission was created in 1879, there were in existence many levee districts empowered by State laws to build levees for their own protection. From that date until passage by Congress of the first Flood Control Act in 1917, these districts carried the burden of flood control in the Alluvial Valley. In 1882, the Mississippi River Commission prescribed levee specifications that included a crown width of 8 feet, except where otherwise directed by the engineer, and side slopes to be as directed by the engineer. Following the flood of 1882, landside slopes which had previously been 1 on 2 were flattened to 1 on 3. In 1896, a new standard prescribed the side slopes to be 1 on 3 for the riverside; the landside was to be 1 on 3 to a point 8 feet below the crown, then 1 on 10 for a distance of 20 feet (the banquette), and then 1 on 4 to the landside toe. The resulting levee proved to be inadequate in the floods of 1912 and 1913. Many of the crevasses were ascribed to overtopping, structural weakness, blowouts, and sand boils. In 1914, the Mississippi River Commission modified the standard by placing the grade at 3 feet above the 1912 high water confined, and the banquette from 5 to 8 feet below the levee crown, with banquette widths from 20 to 40 feet, both depending upon the levee height.

The 1914 levee grades proved to be inadequate in the flood of 1927, and, therefore, an entirely new levee standard was adopted in 1928 that was based on the trapezoidal section without the banquette; that took into account the type of soil used in construction; and that adopted a freeboard of 1 foot above the maximum probable flood, as shown below:

Section	*Crown Width feet*	*Riverside Slope*	*Landside Slope to Contain Seepage Line of:**	*Predominating Material*
A	10	1 on 3	1 on 6	75 percent or more buckshot (clay)
B	10	1 on 3-1/2	1 on 6-1/2	Loam
C	12	1 on 5	1 on 8	75 percent or more sand

* Seepage line was assumed to spring from riverside slope, 1 foot below crown of levee.

In practice, it was found that use of materials rich in clay was undesirable; for that reason, the "A" section was seldom employed. It has been established that, during the period this standard was prescribed,

about 90 percent of levee construction and enlargement utilized the "B" section.

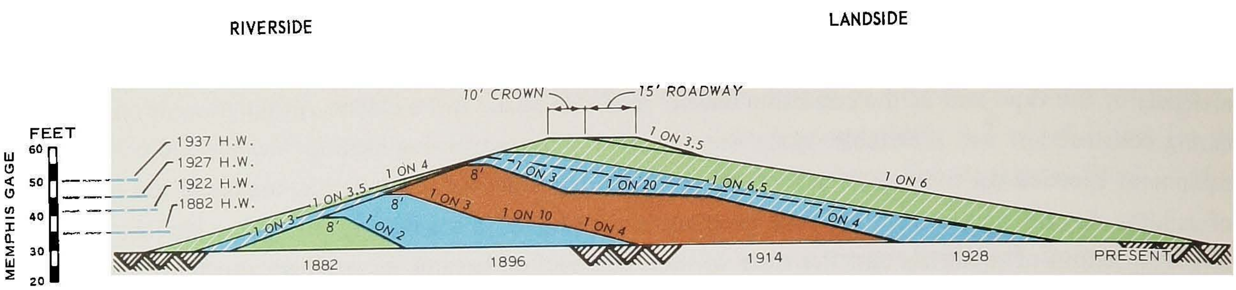
The empirical section design resulted from many years of experience with levees constructed of materials of the type and in the condition usually available in the lower valley. Although some compaction during construction was inevitable, none was specified and control was lacking. Mechanized earthmoving equipment speeded up the rate of placement and this, together with higher fills, increased the possibility of failure. As the new science of soil mechanics developed, the advantage of giving greater attention to the condition of materials and the state of their compaction became increasingly apparent. The revision of the standard section design adopted in 1941 dropped mention of the type of material of construction, but distinguished between sections of levees of compacted and uncompacted material. For compacted material, a seepage line of 1 on 5-1/2 was to be contained in the landside slope; for uncompacted material, the slope was to be 1 on 6-1/2. In both cases, the riverside slope was set at 1 on 3-1/2. Further recognition of the value of compaction was given in April 1947 by issuance of the Mississippi River Commission *Code for Utilization of Soils Data for Levees,* which promulgated three cross sections as depicted below.

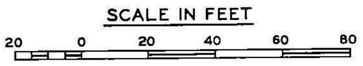
Section Type	*Riverside Slope*	*Crown Width feet*	*Landside Slope*
1	1 on 3-1/2	10	1 on 4-1/2
2*	1 on 4	10	1 on 5-1/2
2**	1 on 4	10	1 on 6
3	1 on 4-1/2	10	1 on 6-1/2

* Less than 25 feet in height.
** Twenty-five feet or more in height.

Selection of the section to be used was governed by the code specifications which set forth the limiting moisture content for various classes of material, estimated for the time of construction. The type 1 section, for new levee construction, required materials to be compacted in layers by continuous operation during construction of a sheepsfoot roller. Control of moisture content was included. A levee of this type was comparable in construction to an earthfill dam. The type 2 section, also for new levee construction, was prescribed with the object of obtaining the maximum practicable compaction of wet soils at least cost and reduction of output. Material at natural water content was permitted, and moderate compaction was required by means of controlled movement of equipment. When casting equipment was used, material placed in the lower two-thirds of the embankment was to be dropped a minimum distance of 10 feet. The type 3 section material for new levee construction and emergency construction was not required to be compacted except for such compaction as might be obtained in dragline construction by dropping a minimum of 10 feet, but such a drop was not required in tower machine construction. In the case of enlargements, the existing levee was to be considered as a semicompacted fill, with crown widths and slopes as appropriate for the type of construction involved. The code also required that an allowance be made for the foundation settlement specifically estimated in each case, and furthermore that allowance be made for consolidation within the levee section. The prescribed shrinkage factors were 5 percent for type 1; 10 percent for type 2; 15 percent for type 3; and 10 percent when hydraulic-fill construction was used.

The sections adopted in 1947 continue in use in 1972. Figure 25 depicts the evolution of the standard levee section from 1882 to 1972.





DIMENSIONS OF CROSS SECTIONS

YEAR	HEIGHT FEET	BASE WIDTH FEET	AREA SQ FEET
1882	9.0	53.0	274
1896	15.5	120.5	951
1914	24.0	200.0	2455
1928	27.0	260.0	3645
PRESENT	30.5	315.0	4956

Figure 25. Evolution of the standard levee section, 1882 to 1972

Seepage control

Writing of the three principal causes of levee failure on the lower Mississippi River, Elliott observed that overtopping was a consequence of miscalculation of possible flood heights, and that bank caving was due to improper location of the structure, and perhaps to a lack of bank protection, as well. There remained seepage through the levee section as the chief factor influencing levee design. He also cited erosion and wave wash as lesser causes of trouble. With the standard sections in use prior to the 1928 section, seepage occurred through the levee section and was a threat to the integrity of the line of protection because it could lead to failure in the levee section proper. Adoption of the larger 1928 section lessened the danger of such crevassing by reducing the danger of seepage through the levee section. Further improvement was brought about by the 1947 section. However, seepage through the levee foundation, which is typically composed of pervious sands with a relatively impervious top stratum of clays or silts, continued to be a troublesome problem during major high water periods. The hydraulic gradient in the sand stratum under the levees resulting from high river stages causes a flow of seepage beneath and landward of the levee. Such seepage emerging at or landward of the levee toe is termed underseepage. Where the foundation and top strata are heterogeneous, as is usually the case, seepage tends to localize instead of causing the entire top stratum to heave or become "quick." A combination of excess head and seepage can create sand boils and subsurface erosion that may culminate in formation of piping beneath the structure with no heaving action. The extent to which underseepage and sand boils may have been responsible for levee failures is not known, as these failures have occurred suddenly, in remote places, unobserved by competent witnesses. Actually, no crevasses on the lower river have been positively attributed to these causes since 1913, although heavy underseepage and sand boils occurred along numerous reaches of levees during the 1937 flood. Subsequently, some of these levees were enlarged and landside seepage berms (essentially integral sublevees) were constructed in known critical reaches.

In 1937, little information was available concerning characteristics of the foundation soils, the relation between geological features and underseepage, or rational methods for analyzing underseepage. Because of this lack, the Mississippi River Commission, in 1940, began a thorough and comprehensive study

of underseepage and its control along the lower Mississippi River levees. The investigation included a review of all underseepage reports made during and since the 1937 high water; exploration and geological studies of numerous sites where underseepage had been a problem in 1937; field installation of piezometers to measure substratum pressures; field pumping tests to determine sand aquifer permeabilities; studies of relief wells, partial cutoffs, and landside berms for underseepage control; and observation and measurement of natural seepage during the 1950 high water. The studies made are described in a report published in 1956. This report includes a description of the geological features pertinent to a consideration of underseepage; an outline of the studies and analyses made, including an evaluation of the data obtained; a description of various seepage-control measures and their design, construction, installation, and maintenance; and a summary of the findings, with a statement of recommendations in the light of the studies made.

The report states that control of underseepage and prevention of sand boils landward of levees founded on deep strata of pervious sands require some means of controlling erosional seepage and of reducing, to a safe value, the excess pressure beneath the landside top stratum. Measures that may be used are impervious riverside blankets, relief wells, landside berms, drainage blankets, drainage trenches, cutoffs, and sublevees. Figure 26 illustrates various methods for control and prevention of underseepage. The choice of method depends on several factors, including nature of foundation, cost, permanency, availability of right-of-way, maintenance, and disposal of seepage water. The principles involved in each are quite different.

If the impervious top stratum riverward of the levee has been removed, placement of an impervious riverside blanket, by increasing the distance from levee to point of entry of seepage, increases the resistance to entry into the pervious substratum, thereby reducing both seepage flow and excess pressure landward of the levee.

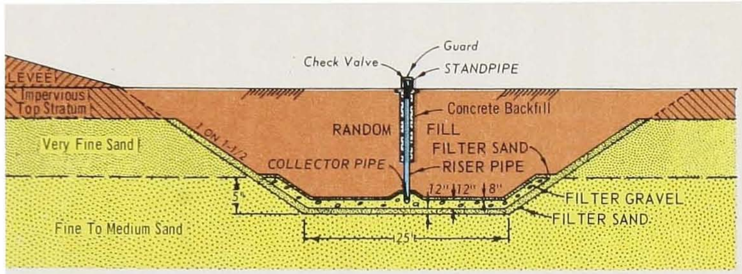
Passage of seepage beneath the levee can be blocked by an impervious cutoff despite existence of a ready entry for seepage into the pervious foundation through the river channel or riverside borrow pit. This method not only avoids the problem of seepage water landward of the levee, but eliminates excess substratum pressures.

Relief wells along the landside toe of a levee do not block the flow of seepage, but when properly spaced and of sufficient penetration, they provide pressure relief and controlled seepage outlets that offer little resistance to flow and prevent erosion of the foundation soil.

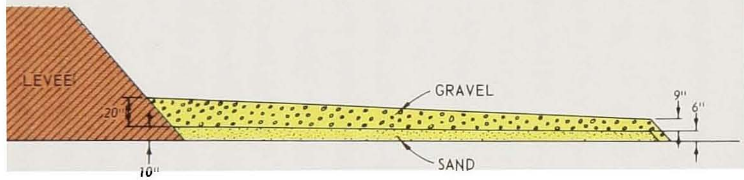
A landside berm controls underseepage by supplementing the top stratum immediately landward of the levee to the extent that the combined weight of the berm and top stratum is sufficient to resist the excess uplift pressures beneath the top stratum. Furthermore, the berm increases the base width of the levee, thereby lengthening the path of seepage flow through the pervious aquifer. The residual excess head at the toe of the berm is then no longer critical, and the emerging seepage or sand boils and piping are moved landward from the levee itself.

Alternatively, the activity and danger of sand boils can be reduced by storage of water in sublevee basins, built to encircle areas known to be susceptible to dangerous underseepage. The weight of the stored water counterbalances the excess head beneath the top stratum in the subleveed area.

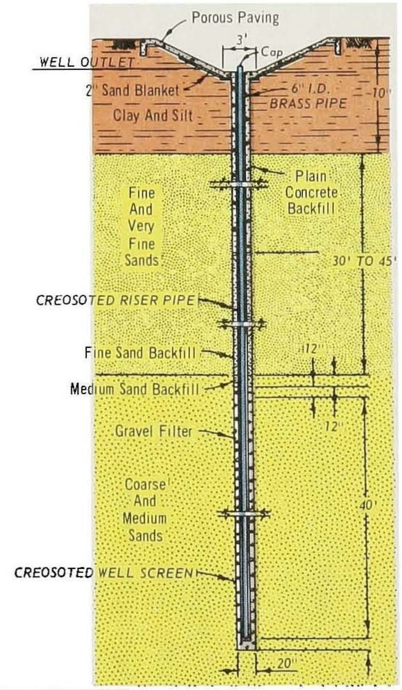
The remaining two measures—landside drainage blankets and landside drainage trenches—effect control of underseepage by intercepting it as it emerges from the pervious substratum without allowing erosion to take place, and also provide a certain amount of pressure reduction landward of levees where the blanket or trench contacts the underlying aquifer. Figure 27 shows a typical levee with a landside seepage berm.



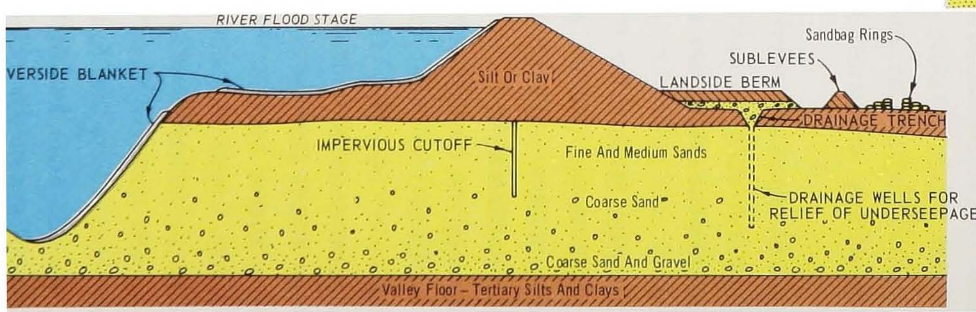
DRAINAGE TRENCH



DRAINAGE BLANKET



RELIEF WELL AND COLLECTOR DITCH



TYPICAL LEVEE SECTION SHOWING
CONTROL AND PREVENTION OF UNDERSEEPAGE

Figure 26. Methods for control and prevention of levee underseepage

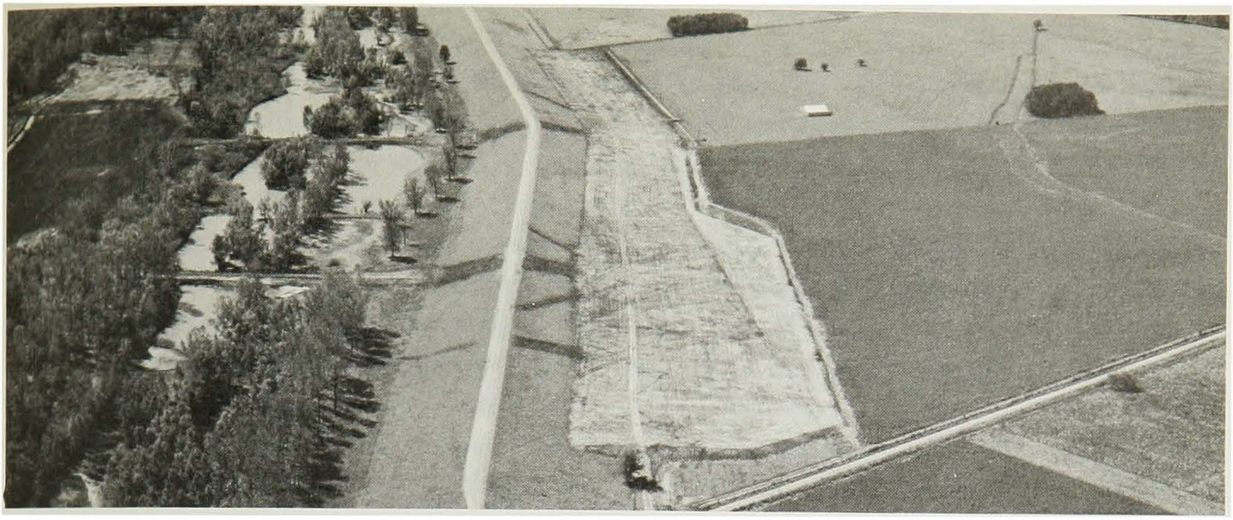


Figure 27. Typical levee with landside berm

Cutoffs constructed of earth, of steel sheet piling, or by grouting on close centers may be located under the levee for new construction, or at the riverside toe for existing structures. When properly designed and constructed, they are the most positive means of underseepage control. However, they will not reduce seepage and excess pressures significantly unless they penetrate 95 percent or more of the pervious aquifer, and constructing them to depths of 80 to 200 feet is not economically feasible.

Construction of sublevees around critical seepage areas requires proper foundation preparation and use of relatively impervious soil placed in lifts and compacted. Paved overflow spillways and a gated outlet are required. Basins longer than 300 to 500 feet should have cross dikes, and both the sublevees and cross dikes should be sodded and maintained. A serious defect of this method is that in case sand boils should develop within the basin, it might be difficult to detect and consequently to deal with them. Control of seepage by this means might call for manipulation of water levels during high water periods. Moreover, it is to be noted that failure of a sublevee when the basin is filled would result in loss of the counterhead at a critical time.

Since the intended functioning of a drainage blanket requires it to be pervious, it is inadvisable to construct such a blanket until the landside levee slope has been stabilized and sodded sufficiently to prevent clogging of the blanket by soil eroded from the slope. A drainage blanket should not be constructed unless the pervious foundation extends completely to the surface. The blanket is not effective for controlling seepage from deep substrata where impervious strata, or even stratified fine sands, exist between the drain and the deeper, more pervious sands. Consequently, drainage blankets are generally unsuitable for control of underseepage along levees in the lower Mississippi River Valley because typically a top strata of clays, silts, or fine sands overlie the deeper and much more pervious aquifer.

To be effective, drainage trenches must be excavated deep enough to penetrate any upper impervious strata. They are usually excavated just landward of the levee toe. The trench filter layers must be properly graded and carefully placed with a perforated collector pipe and risers. Such trenches can be used to control underseepage where the top stratum is thin and the pervious foundation is of limited depth so that the trench will substantially penetrate the formation. When the pervious foundation is deep, a drainage trench of any reasonable depth would attract only a small portion of underseepage; hence its effect would be local and detrimental underseepage would bypass it. Because of the great depth

of the pervious substratum along the main stem, drainage trenches are considered infeasible for these levees.

Relief wells were reputedly first used by Indian engineers of the Punjab Irrigation District, Punjab, India. In 1942 and 1943, experimental relief wells were installed along the Mississippi River levees at Commerce and Trotters, Mississippi, and at Wilson Point, Louisiana, where underseepage had been a problem during the 1937 flood, and where foundation explorations had already been made. Piezometers were installed at all sites to aid in evaluating the performance. The installation at Commerce was made to study the effectiveness of different screen penetrations into the underlying pervious aquifer. Although the systems operated during the 1943 high water, the wells were found to be too small in diameter and so they were plugged or pulled. In 1950, a new well system and additional piezometers were installed at Trotters in order to make a full-scale field test of the efficacy of a larger capacity relief-well system. This installation functioned satisfactorily during the 1951 and 1952 high water periods. Piezometer readings and seepage observations indicated that the well system reduced substratum hydrostatic pressures landward of the levee to a small fraction of the head on the levee, and also intercepted a large portion of natural seepage which otherwise would have emerged landward of the levee. Concurrently with tests of relief wells along Mississippi River levees, installations were made of wells at the toes of earthfill dams in the Yazoo Basin and elsewhere. These led to modifications in design and specification, and development of drilling and casing techniques for their installation. A typical relief well consists of a slotted wooden well screen and riser pipe, with gravel filter to the top of the well screen; with sand backfill to an elevation 10 feet below the well outlet; and with concrete backfill from the top of the sand backfill to the finished ground surface. The wells are installed in a hole drilled by the reverse rotary method, the casing method, or any method that will not remove excess material from the foundation. The length of the well screen is dependent upon the percentage of effectiveness penetration of the pervious aquifer used in design of the well system. The wells should penetrate the principal pervious stratum to obtain efficient relief of pressure. They should offer little resistance to water flowing through the screen and out of the well; they must be so constructed as to prevent infiltration of sand, and to resist the deteriorative action of soil and water. Relief wells have several disadvantages. They require periodic inspection and maintenance; they must be protected from back flooding; and they increase the total quantity of seepage about 20 to 40 percent. The problem of water removal might be substantial—in some instances, it might have to be returned to the riverside by pumping over the levee. These disadvantages can be overcome, to some extent, by providing the wells with suitable guards, check valves, and standpipes to prevent flow during low flood stages.

Riverside blankets should be constructed of the most impervious material economically available. The material should be placed in lifts and compacted. The thickness of the blanket depends upon permeability of the material used, but it should be a minimum of 3 to 5 feet. Borrow pits that have been excavated to sand for levee construction can be partially refilled with silt by constructing dikes properly located along the levee. A blanket formed by this means will not be as impervious as a compacted clay blanket, but will substantially reduce underseepage and hydrostatic pressures landward of a levee.

Landside seepage berms should be sufficiently wide to insure that the head at the berm toe is no longer critical. They may vary in type from impervious to completely free draining. Selection of the type to use is based on availability of borrow materials and the relative cost of each type. An impervious seepage berm restricts the natural relief of pressure that would result from seepage through the top stratum and thus increases the hydrostatic head at the levee toe with respect to the original ground surface. The effect of an impervious berm on substratum pressures is equivalent to increasing

the base of the levee an amount equal to the width of the berm. A semipervious berm is one in which the vertical permeability is equal to that of the top stratum. Natural seepage will pass through such a berm and emerge on its surface. A sand berm should have a vertical permeability such that seepage into the berm will emerge at its surface, as sand berms do not have sufficient capacity to conduct appreciable flow landward. A free-draining berm is one where the seepage enters the berm, and is collected and discharged landward with low internal head losses in the berm. Such a berm will not affect the natural seepage flow pattern or distribution of landside substratum pressures. It will therefore be the narrowest and thinnest of all berms required for a given foundation condition. Such a berm should be underlaid by sand and gravel filters and a collection system.

The 1956 underseepage report offered five recommendations based on technical conclusions of the report as follows:

a. All of the berms in the three Districts should be investigated with regard to underseepage, using the procedures, methods, and criteria for safety set forth in the report.

b. New or additional control measures should be designed, constructed, or installed, and properly maintained where such investigations so indicate.

c. Geological and soil conditions have an important bearing on underseepage and should be given careful consideration in locations of new levees.

d. The effect of borrow operations on the seepage problem and required control measures should be considered in design and construction of a levee.

e. The piezometer installations made in connection with the report investigations should be maintained and observed during significant high waters, and the data analyzed as they become available. The natural seepage should also be observed at or near the crest of future high waters at the sites where it was measured in 1950.

As of 1972, seepage berms have been constructed at the locations that were indicated as critical by the 1937 flood and those since then. Construction of these berms is being continued at the locations where field analyses, based on data obtained from the comprehensive underseepage investigation, show that underseepage might be critical if the levee is subjected to the project flood. Present practice is to construct the berms of random material. The other measures discussed in the 1956 study report have not been used on the Mississippi River main-stem levees.

Access roadways on levees

During periods of high water on the Mississippi River, levees are routinely patrolled for the purpose of detecting and promptly correcting any weakness that might develop. In most instances, correction requires construction material to be hauled in. Except for urban areas and those reaches where all-weather roads provide adequate access at close intervals, a roadway on the levee is required for inspection and flood-fighting operations. The act of 15 June 1936 took cognizance of this need by authorizing the expenditure of $4,000,000 over a 6-year period for the purpose of gradually improving the deficiencies then existing. Experience with the 1937 flood emphasized the urgent need for extension of levee roadways to assure that all parts of the levee system could be reached. To provide for such betterment, the 1938 Flood Control Act increased the authorization for roadways on the levees in the amount of $18,000,000.

Prior to the 1936 legislation, the Mississippi River Commission's concern with respect to highways on levee embankments or levee rights-of-way was expressed in the stipulation that such highways should be so constructed and maintained that they would not become a menace to the safety of the levee line. After authorization of the levee roadways, the Commission adopted a policy that access roads should be provided, in cooperation with State and local interests, so that all levees can be reached at reasonably

close intervals by all-weather roads. The 10-foot crown width of the standard levee section is not sufficient for roadway needs. In the interest of economy, as well as to minimize disturbance of a completed and sodded embankment, an increase in width is obtained by a small fill added to the landside of the levee. For main Mississippi River levees, this addition is 15 feet to the top width added on the landward side, bringing the levee top width to 25 feet, with slope of 1 on 3-1/2 to toe-out on the landside levee slope. The all-weather roadway consists of a gravel or crushed stone course 16 feet in width and spread 9 inches deep before compaction. For tributary and backwater levees, a total crown width not less than 14 feet is provided. Widening of the levee crown has customarily been done concurrently with enlargement, setback, or berm construction. However, available funds have been used principally for bringing the entire levee system to project grade and section. Federal funds have been used for the purchase of road materials in those instances where local interests have agreed to construct the roadway.

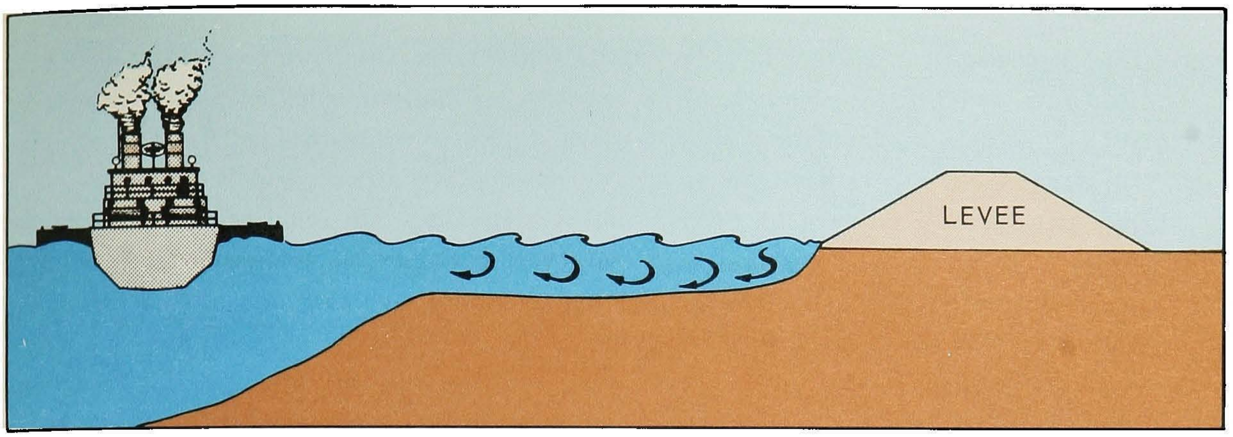
Protection of levee slopes and foreshore

Levee slopes

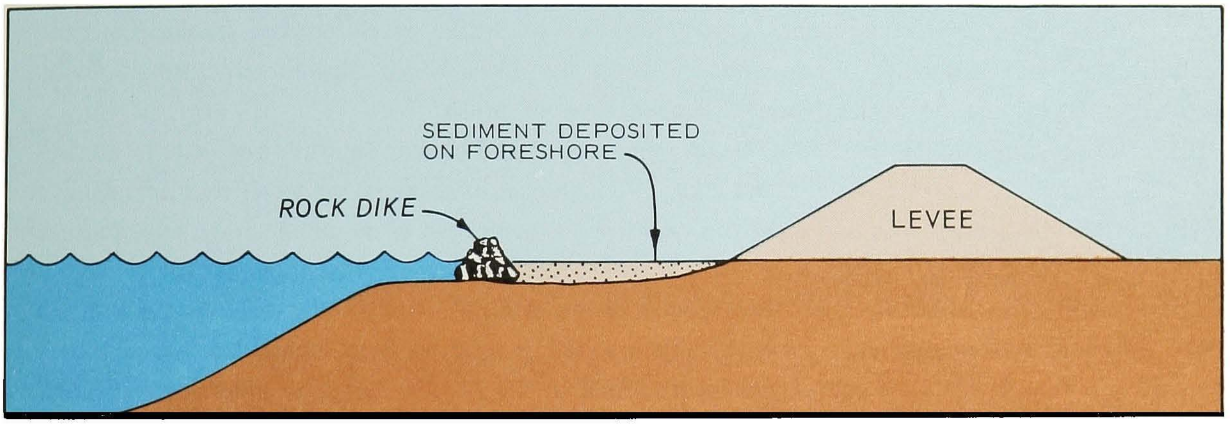
Many miles of the controlling main-line levees are located a considerable distance back from the riverbank where a screen of heavy vegetation shields the riverside slope from erosion by currents and waves. A good sod growth, properly maintained, will adequately protect both slopes from rainwash. If a reach is exposed to erosive currents, it may be necessary to place spur dikes to deflect damaging currents away from the levee.

On the lower reaches of the river, generally below New Orleans, levees may be exposed to waves caused by wind and passing ships. The resulting wave-wash damages may be severe if the area between the low water shoreline and the riverside toe of the levee, termed the foreshore, is narrow and there is no protective timber growth. In such locations, a positive means of levee slope protection must be provided. Measures that have been used include wooden fence revetment, asphalt pavement, and concrete pavement. Of these, concrete slope paving furnishes the most effective and durable protection. It is therefore the principal type currently used. The pavement has an average thickness of 4 inches. At the toe of the slope, the slab is embedded at least 3 feet below the natural ground surface. At the top of the slab, a cutoff wall is incorporated to prevent undermining of the pavement by rainwater drainage from the upper slope area. Both compacted asphaltic pavement and uncompacted asphaltic pavement, the latter developed during World War II as an alternative requiring a minimum of labor and equipment, were found to lack the strength to withstand battering by drift and to disintegrate with age and develop other deficiencies; consequently they are not used.

Only a small part of the levee line above Baton Rouge requires wave-wash protection; hence no permanent protection of this type has been installed above that point. The river below Baton Rouge comprises a great harbor area, plied by oceangoing vessels as well as barge tows. Vessel traffic and barge traffic have increased more than fivefold since 1931, and the speed and tonnage of vessels have also increased. This compounding of the frequency and force of waves generated by passage of vessels has greatly increased the severity of manmade wave attack on the riverbank and levees, which are located very close to the top of bank in this reach. Below Bonnet Carré, the relatively narrow foreshore lies about at the elevation of the average low water plane (ALWP), hence it is exposed to yearlong attack that erodes the levee slope and endangers the levee by eroding the top of bank, exposing the toe of the levee to wave action. Below Baton Rouge, about 84 miles of levee has been protected by asphalt or concrete slope paving. It is estimated that as much as 10 percent of the levee between Baton Rouge and New Orleans, and about 75 percent below New Orleans, should have slope protection.



a. Foreshore attack



b. Foreshore protection

Figure 28. Foreshore attack and protection

Foreshore

Waves generated by passage of vessels likewise erode the riverbank and reduce the width of the foreshore (see figure 28). Evidence indicates that relatively little damage is due to wind-generated waves. Only the riverbank above an elevation 1 to 2 feet below the average low water plane is affected. The rate of erosion is relatively rapid below New Orleans where the banks are, in general, less than 3 feet above the average low water plane and thus are exposed to waves during the long, low water periods, and where the vessel traffic is heaviest. In this reach, the typical eroded bank has a horizontal underwater bench extending landward from the riverbank terminating in a roughly vertical face which, if allowed to extend to the levee, may undermine it and the protective pavement. Upstream from New Orleans, riverbank heights may vary from the 3 feet above average low water near New Orleans to an average of 35 feet in the Baton Rouge area. The higher banks are exposed continuously to erosion, except during flood stages high enough to inundate the bank and protect it. The eroded foreshore in that area is characterized by the terraced bank resulting from wave action during long periods of relatively uniform stages during a general rise or fall.

If foreshore erosion is not controlled, the levee and its protective works may be damaged. Moreover, if substantial removal of the natural berm occurs, the levee stability may be affected. Erosion repairs may be difficult and costly, particularly in case temporary work has to be done during rising river stages,

necessitating permanent repairs during the following low water season. The growing industrial development above New Orleans requires that protection of the valuable riverfront properties be assured. It is apparent now that almost continuous foreshore protective works are needed below New Orleans and that, in the foreseeable future, similar protection will be needed between New Orleans and Baton Rouge.

Initial control efforts centered on development of a structure that could be constructed on the eroded bench in several feet of water; that would arrest further foreshore erosion; and that would cause deposition in the foreshore area. Brush dikes appeared promising and were first used in 1950. They were formed by driving a double row of willow pole piles and filling the space between with willow brush which was secured by steel cable crossties and a lacing fastened by railroad spikes. These dikes were aligned generally parallel to the levee and, insofar as practicable, so placed on the underwater bench formed by foreshore erosion as to aid construction operations by floating plant. Although they functioned as intended by stopping erosion and inducing deposits, the dikes were failures because they required excessive maintenance and had a short life. Physical failures, apparent by 1953, occurred not only by loss of brush filling as a consequence of deterioration of brush, which resulted in slackening of the cable ties, but also as a result of wave erosion under the dikes, which allowed settlement of the brush and slackening of the tie cables, with consequent loss of brush.

The effectiveness of the brush dike in stopping erosion and causing deposition of material established the practicability of a plan using a lateral dike. The high cost of stone in the lower river area eliminated from consideration the use of riprap in the quantities expected to be required. Some experimentation with debris from demolition sites established broken concrete to be a satisfactory substitute for riprap. Ample quantities of such material were expected to be available. Use of this material was initiated in 1954. Although broken concrete is an acceptable material, it has now been superseded by riprap because its cost is lower. A shell-base course was incorporated in the section design to minimize settlement on soft foundations. To form the lateral dike with trapezoidal sections, a minimum thickness of 18 inches of riprap was provided on the exposed slope and crown, and at least 12 inches on the protected slope. Side slopes of 1 on 2 were obtained by dumping without hand placement. A crown width of not less than 3 feet was adopted. Pieces of concrete weighing in excess of 100 pounds were used in construction of the crown, to prevent displacement by wave action. Cross dikes, generally 1 foot lower than main dikes, were located to take maximum advantage of configuration of the foreshore. The spacing averages about 1,000 feet. Figure 29 shows a typical foreshore protection dike below New Orleans.

The riprap dike is effective in stopping further erosion and in inducing refill of the eroded area it contains, and its use is essential where reconstitution of foreshore is required for safety of the levee.

Damage by foreshore erosion must be prevented for practical and economic reasons. Protective work will be required almost continuously along both banks of the river below New Orleans. If industrial growth between New Orleans and Baton Rouge continues at the rate evident in recent years, nearly continuous protection will also be required in that area in the near future. Although the costs will be high, destruction of the levee and its wave-wash protection would necessitate reconstruction on a site far enough from the river to assure a reasonable life expectancy. Reconstruction costs, including rights-of-way, would total many times the cost of protection work. Of course, each such reconstruction would destroy another increment of the most valuable and productive land. Moreover, in developed areas, reconstruction costs would include relocation of highways, railroads, industrial improvements, and other betterments, bringing the total reconstruction cost to a considerably higher figure than that of the protection work.

Figure 29. Typical foreshore protection dike below New Orleans

Atchafalaya Basin Floodway protection levees

The Flood Control Act of 15 June 1936 authorized immediate completion of the Atchafalaya Basin protection levees so as to afford full protection to all lands outside these levees. This work was thereupon prosecuted with such vigor that the Commission could report within a few years that both the east and west lines had been sufficiently completed to furnish flood protection, except for a few small gaps that could be readily closed in an emergency. However, the levees in the lower half of the basin were built on such weak foundations that it was not possible to bring them up to grade—they settled gradually after each raise. The problem was aggravated by the fact that continuing deposition of sediment in the lower floodway area caused loss of floodway capacity and raised the design flow line about 3 feet, which, in turn, required that the grade of the protection levees be raised by the same amount. At this time, the capacity of the floodway approximates 80 percent of the design flood. The levee could be raised in an emergency. However, full capacity will not be obtained until the floodwalls at Morgan City and Berwick are raised and provisions are made to raise the locks and floodgates.

The alluvial and deltaic plain of the Mississippi River, in which the Atchafalaya Basin levees are located, is an area of low relief. Ground surface elevations referred to mean sea level range from about 50 feet at the basin's northern boundary to 1 or 2 feet in the southern part. The soil deposits consist of a substratum of sand and a top stratum of fine-grained, relatively impervious silts, clays, and silty sand. In the northern portion of the basin, the top stratum is 90 feet thick, and consists of fairly strong clay. Because foundation conditions are relatively good, great difficulties were not experienced in building levees to prescribed grade and section. In the southern portion, the top stratum thickness is about 140 feet

and its upper 45 to 50 feet consist of backswamp and marsh deposits of very soft plastic clay and organic clays and peat, all of which are highly compressible with low shear strengths. For levees on both sides of the floodway below the approximate latitude of the lower end of the Atchafalaya River levees, settlement and stability of the embankment have been continuing problems. Attempts to bring the line of protection to grade have been in progress for the past 25 to 30 years. These attempts have been hampered by sedimentation, which necessitated raising the grade to which the levees were to be built, and by foundation settlement. In some reaches of the east basin levee, the weight of the fill has caused the levee and foundation to sink as much as 20 feet. The average settlement is about 13 feet.

Many studies and tests have been conducted in the effort to develop a way of building the levees safely and as rapidly as possible. A method employed in early practice consisted of placing a hydraulic fill, shaping it into a levee, pumping more fill and shaping it, and then raising the crown by adding small increments of fill, ranging from 6 inches to 2 feet, thereby gradually loading the foundation. After each lift had been placed, sufficient time had to be allowed for that lift to consolidate and strengthen so that the next lift could be added without inducing a shear failure in the levee foundation. This was a time-consuming procedure and, at best, only a very small net increase in levee grade was achieved because of the offsetting settlement induced by each lift. By such a gradual process, an extremely long period would be required to complete the raises, an intolerable prospect because of the importance of having in existence the planned flood protection.

In 1963, a plan devised to reduce this time requirement was adopted. It contemplates two distinct phases. The first phase consists of raising the existing levees in one lift with a wide crown to a gross interim grade which generally is at or above the new design flow line, using large stability berms of hydraulically placed fill. The function of the berms is prevention of shear failures of the foundation by reducing the calculated foundation shearing stress to a safe value. The second phase, to follow as soon as the initial fill has consolidated and strengthened the foundation, consists of raising the levees to the ultimate grade, followed by placing material on the levee crown in successive thin lifts at intervals of several years, to compensate for settlement.

With the object of testing the adequacy of this procedure, and to secure engineering data on settlement and horizontal deformation of levees and foundations, three test sections were constructed in the east protection levee in 1964 and 1965. The first of these sections followed the first phase of the adopted plan, with large stability berms designed for a factor of safety of 1.3. The second test section was similar except for slightly smaller berms estimated to be required for a factor of safety of 1.1. Both of these sections were constructed with a wide crown at an interim grade of 4.5 feet above the flow line. The third test section was a small narrow crown embankment constructed on the crown of the existing levee, considered as a possibility for providing an interim degree of protection in some of the worst areas. It had an estimated factor of safety of 1.1, and had no stability berms. Observations of the first two test sections showed differential settlement and cracking of the wide levee crown and progressive movement toward the floodwayside. The section designed according to the adopted plan, with a factor of safety of 1.3, moved less than the section with a factor of safety of 1.1. Observations are continuing.

An additional test fill of hauled-in and compacted material, with a safety factor of 1.3, has been constructed. To date, settlements have been less than those at the test section with hydraulic fill berms and a safety factor of 1.3.

The test-section data indicate that a safety factor greater than 1.3 must be used to reduce loss

of grade caused by lateral deformations and creep of the foundation soils. This will be achieved with existing berms and by reducing the ultimate crown width of the levee embankment from 20 feet to 10 feet. The data also show that foundation consolidation and gain in shear strength occur slowly. Thus, even with the large stability berms and narrower crown levee, considerable time will be required to complete these levees. However, protection to the design flow line will be obtained well in advance of completion of the levees.

Levee safety investigations

In the discussion of studies of Mississippi River levee design, it was apparent that levee cross sections had evolved before sufficient development of the science of soil mechanics had occurred for application to the design. The empirical design resulted from years of experience in constructing levees with material of type and condition usually available at the site. Control over placement, insofar as its classification and moisture content were concerned, had not been exercised. Over the years, changes in cross section and in specifications had occurred, and, in many cases, existing levees were incorporated into new work. Although such completed works had successfully passed a number of floods, they had not withstood floods approaching the project flood.

With the purpose of investigating the adequacy of current standards for levee design and construction, and of determining if they result in a stable levee section, the Mississippi River Commission, in 1963, began a study of the safety of the main-stem levees, which is still in progress. The scope of the study includes examination and analysis of the stability of existing levees and remedy of any inadequacy discovered in order to insure that the entire levee system, adequately maintained, will withstand the project flood and safeguard lives and investments in the Alluvial Valley.

An initial general evaluation of levee conditions showed that all levees are to adopted grade and section except for certain reaches in the New Orleans District. These were not Federally constructed, and although they do not conform in section to the present standard, a program has been adopted for converting them to standard section. A number of slides have occurred within the past 30 years, but only one, at Free Nigger Point, in 1949, resulted in loss of integrity of the levee (see figures 30 and 31). This failure, which took place during a high water stage and was attributed to a flow slide which undermined the riverbank and levee foundation, is described in more detail under the heading, "Levee Crevasses." During the 30-year period, there have been recorded some 165 shallow slides, usually confined to the levee section and not involving the foundation. Most of these occurred in the riverside levee slopes and were apparently caused by alternate wetting and drying, with failure occurring when the material was very wet and had low shear strength. Such incidents are not a menace to levee safety, but they are a nuisance as they add to the maintenance operations. Repairs are made by replacing the wet material with drier soil, after which the levee slope is flattened or a riverside berm is added.

Within the period, there have also been 49 deep slides involving the foundation. As these have occurred during construction or shortly after completion, they are attributed to loading of the foundation in such manner as to produce shear stresses in excess of the quick shear strength. They can now be prevented by appropriate use of exploratory, testing, and design techniques of soil mechanics.

The levee safety investigation program includes stability studies of typical sections of existing levees, using assumed values for embankment and foundation shear strengths, to establish criteria for identifying potentially critical reaches. These assumed values are based on shear tests from undisturbed borings made at typical levee reaches. An examination will then be made of the entire levee system to locate critical reaches. For those reaches, detailed explorations, tests, and design analyses will be made to determine

Figure 30. Free Nigger Point crevasse, 1949

Figure 31. Temporary closure of Free Nigger Point crevasse

the stability and corrective measures required. Those levees found to be inadequate will be strengthened.

The levee safety study is considered to be the most important aspect of the main-line levee feature of the Mississippi River and Tributaries Project.

Potamology Investigations

Inception of investigations

The bank protection experiments made by the Mississippi River Commission as early as 1879 have already been mentioned. Various investigations made since 1931 of means of achieving the broad objective of stabilizing the river in a suitable alignment at lower costs have also been described. Included were the laboratory meander study, laboratory and prototype examinations of the V-type articulated revetment mat, various uses of asphalt as bank protection or for closure of concrete mat interstices, and the analytical and hydraulic laboratory studies of cutoffs. In addition, several auxiliary investigations related to the principal program then in progress have been conducted. From 1932 to 1935 an effort was made to determine the most favorable alignment in which to stabilize the Mississippi River in prosecuting the cutoff program then being initiated. The object was to determine by hydraulic model experimentation the length of tangent distance through which the main river will maintain itself between consecutive curves. A major qualitative conclusion drawn from the study, which was terminated before all programmed tests had been completed, was that the greater the rate at which bedload was supplied to the first bend, the greater the radii of the bends and the more rapidly they developed.

A survey to determine the composition of bed materials in the main stem was made in the fall of 1932, and 531 samples were taken from the thalweg between Cairo and New Orleans. An additional 143 samples were obtained from the beds of the Ohio, Atchafalaya, Old, Black, and Red Rivers. Early in 1934, 84 thalweg samples were taken between New Orleans and the Gulf of Mexico, and from the principal passes at the mouth of the Mississippi River and several minor outlets. From the results of a mechanical analysis made of each sample, a graph was plotted of the variation in mean grain size of sand only in the main-stem bed materials. Besides depicting the progressively decreasing grain size with distance below Cairo, the graph showed the influence of the bed material being supplied by several of the large tributary rivers.

Sediment-load estimates were made between 1932 and 1938 by means of suspended load sediment traps placed in the river at Mayersville, Mississippi, and in 1938 by sampling in the vicinity of Head of Passes. Analyses of the Mayersville samples indicated that the sand in transport past this range averaged about 550,000 cubic yards per day. The maximum rate, measured just before the crest of the 1937 flood, was about 1,870,000 cubic yards per day. These figures include only that part of the sand load in suspension that could be caught in the sediment traps and do not include the major part of what is considered to be bedload. The measured sand transport in the three principal passes combined was on the order of 90,000 to 100,000 cubic yards per day.

From mid-1940 until late 1941 an investigation similar to the 1932-35 study previously described was conducted to determine the most favorable alignment in which to stabilize the river in prosecuting the cutoff program. The purposes of this investigation were to obtain specific data on the natural tendencies of a model stream with regard to development and maintenance of a definite meander pattern, and to study methods of controlling and directing these natural tendencies in connection with the solution of various practical river problems. Although this study was terminated abruptly by the entry of the

United States into World War II, it actually formed the foundation for the later research program on the meander phenomenon, described under "Channel Stabilization Investigations," that was begun in 1942 and completed in 1944.

The program of channel improvement and stabilization authorized by the 1944 act was based, to a large extent, on the findings of the meander phenomenon research. Progress under this authorization was severely limited by wartime restrictions. With the ending of the war, full-scale planning for civil works was resumed. In 1946 a comprehensive research program, designated "Potamology Investigations," was undertaken in office, laboratory, and field. The program had the following main objectives:

a. To study the meandering tendencies of the Mississippi River with a view to development of a model and model-operating technique that could be used to predict future changes within a specific reach of the river.

b. To determine the nature of revetment failures, their causes, and methods of preventing such failures.

c. To study and develop methods of channel stabilization by means other than the use of revetment.

d. To develop and test comprehensive plans for the improvement of specific troublesome reaches of the river.

The Waterways Experiment Station was assigned responsibility for the investigations, with the cooperation and assistance of the staffs of the Mississippi River Commission and the three District offices. A complete technical and administrative task force was established at the Waterways Experiment Station for the project. The work was actively prosecuted from late 1946 to the summer of 1951. Extensive field observations were made at several points on the Mississippi River. Several large-scale laboratory projects were conducted by the Hydraulics Laboratory of the Experiment Station. Coordinated activities were conducted by the Soils and Pavements Laboratory and its Geology Branch, with development of special instruments by the Instrumentation Division. A board of consultants was established to cover all aspects of the investigation.

During the course of, and following, the extensive field and laboratory work, about 50 interim and final reports of the various phases of the project were prepared. In addition, other reports were prepared during this period of emergency investigations which arose from revetment failures but were not a part of the potamology program.

In the fall of 1946, a major failure of revetment occurred in Reid-Bedford Bend, a few miles below Vicksburg. This revetment had been placed earlier that year on the actively caving right bank. Within a few hours, the failure removed several hundred thousand yards of material and several hundred feet of revetment. As the cause could not readily be determined, decision was made to conduct a model study which, it was hoped, would demonstrate actual failure of a revetment, leading to determination of the causes of revetment failures and methods of overcoming them. Early in 1947, two additional major failures occurred in the same revetment (see figure 32). These circumstances had a great deal to do with setting up the potamology investigation program, and the proposed model study was incorporated into that program under the foregoing main objective designated *b*.

Hydraulic forces operating in river

At an early stage of the investigations, it was realized that knowledge of the magnitude of hydraulic forces operating in the river is intrinsic to resolution of the problem of stabilizing the river's banks. Turbulent flow is a significant element in phenomena related to the problem, including transportation of bedload and suspended load, bank caving, bar building, major meandering, and bend migration resulting

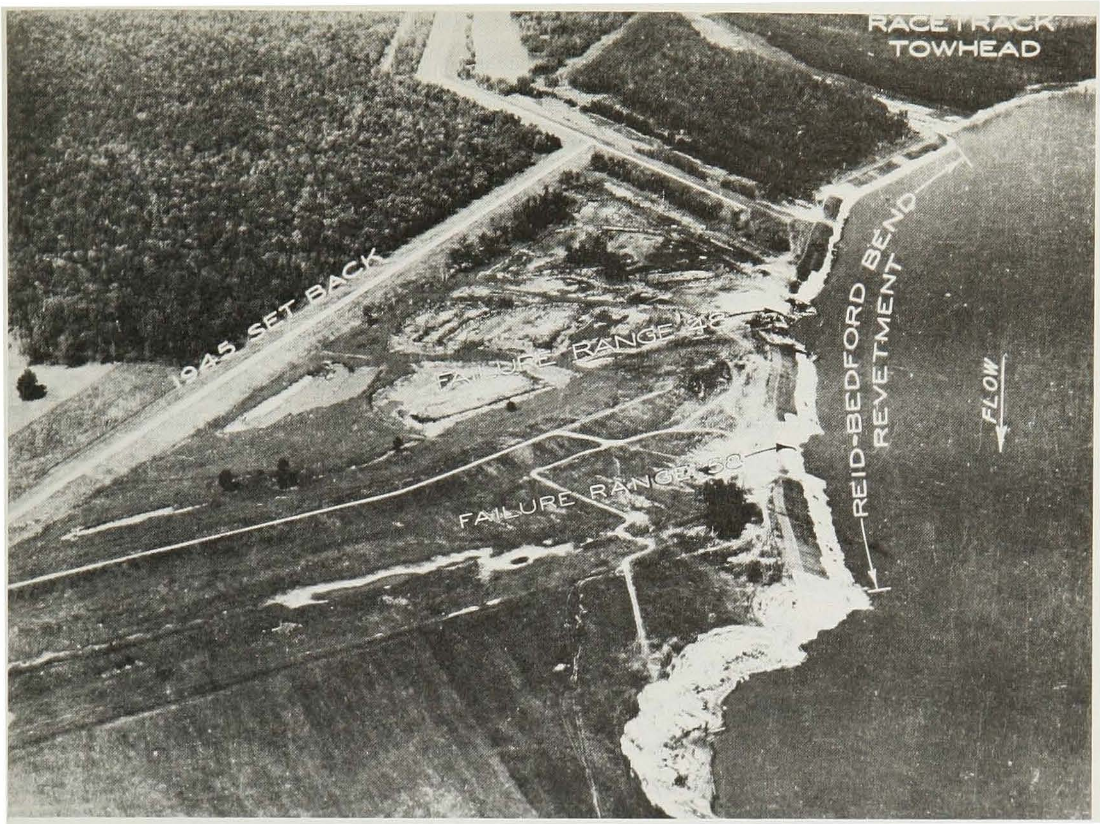


Figure 32. Failures in revetted bank at Reid-Bedford Bend

from a combination of the foregoing factors, and variations in elevation of river bottom, with changes in stage and discharge. Accordingly, the planned program included direct measurements of pressure fluctuations, at and near the bottom of the river, produced by turbulence; determination of the rate of transmittal of such pressure fluctuations to the underside of revetments; measurement of velocity fluctuations, particularly at or near the bottom of the river, to be correlated with the pressure measurements, if possible; instantaneous determinations of the directions of currents near the bottom of the river, to be correlated, if possible, with the velocity and pressure measurements; and determination of the spatial extent of the turbulence patterns, both vertically and horizontally.

Not all the original objectives of this phase of the potamology investigations were attained because the program was halted at the end of Fiscal Year 1951, partly because of a shortage of funds.

Investigation of major bank and revetment failures

At the time of inception of the potamology investigations, the mechanism which could cause hundreds of thousands—or even millions—of cubic yards of material to slide into the river in a period of hours, or perhaps only minutes, was not known. A major effort was therefore directed to this aspect of the overall program. Exhaustive field investigations, supplemented by laboratory tests, led to the conclusion that such major bank and revetment failures can only be explained as "flow slides." When certain unfavorable conditions of bank-material components, thicknesses of strata, and internal pore pressures exist, some triggering mechanism can cause an entire mass of sand to become almost liquefied instantly, with the result that the mass will flow into the river as a semiliquid. Detailed study of soil conditions has shown certain characteristics that create a susceptibility to flow slides. Liquefaction failures occur

in point-bar deposits, which usually contain three basic soil types: a somewhat cohesive overburden; underlying fine sands, termed the "upper sand series"; and, in turn, underlying coarse sands and gravels termed the "lower sand series." The upper sand series can be subdivided into two zones on the basis of variations in grain size, natural density, and penetration resistance, as determined by the rotary cone penetrometer (see discussion under "Potamology study program (1957-1961)"). The stability of a slope is dependent upon the relative thicknesses of the overburden and the top stratum of fine sand in the upper sand series. When failures have occurred, the boundary between the two zones has been found to correspond approximately to the depth of failure. Liquefaction failures have not been known to extend into the lower sand series.

The hypothesis that attributes major bank failure to flow slides is now generally accepted. It is further recognized that when a susceptibility to flow slides exists, some triggering action must take place to cause failure. Among other possible factors, that action might involve hydraulic forces, such as turbulence adjacent to the susceptible bank and scour at the toe of the bank, resulting in steepening of the bank.

Growing out of this phase of the potamology investigations were suggested ways of dealing with potential flow slides in riverbanks. The procedure first called for making borings, taking samples, and analyzing data in accordance with established criteria to ascertain the location of unstable banks. The recommended measures covered several alternative courses of action. If the extent of the unstable sand deposit was small, the material would be left for natural processes to remove and thereby expose more stable soil, or perhaps to make a minor levee setback in lieu of attempting to prevent a bank failure by placement of revetment. For larger deposits, several ways of accomplishing partial stabilization were recommended. Advance grading for revetment, such as flattening the steep slopes in overburden deposits, was one suggested possibility. Another method was to cause preventive failures, either by dredging or by use of explosives, which seemed to have merit in view of the fact that experience indicates that the potential danger of flow failure in once-failed or remolded stratified sands is smaller than in undisturbed soils. In some cases, partial stabilization might be obtained by compacting the soil, by means of vertical drainage of the sands of the upper zone, or by grouting.

A summary report of soil studies made by the Waterways Experiment Station in 1952 included the recommendation that the criteria of bank stabilization developed in the soils phases of the potamology investigations be used in future analyses of soil conditions at sites where revetments were planned. This procedure was adopted by the Mississippi River Commission, and arrangements were made for the Districts to forward the results of all revetment-boring investigations to the Waterways Experiment Station for analysis pursuant to the adopted criteria. It was intended that, when susceptibility to a flow slide was predicted for a site, further study would be made and perhaps one of the preventive measures would be taken prior to placement of the revetment. The program of analysis of revetment borings has been carried out since 1954, and the Waterways Experiment Station has annually summarized the results of the analyses for the preceding year. During that period, flow failures have occurred at a number of boring locations and most of those locations were predicted to be unstable. A few failures have occurred at boring locations for which no prediction could be made, since the full depth of the upper sand zone was not determined during the field investigation. Although one flow failure occurred near a boring location predicted to be stable, the failure was located more than 800 feet from the boring, and the boring data might not be representative of soil conditions at the failure location.

Thus it appears that the classification criteria have proved reliable in predicting susceptibility to flow failure. Of course, many new locations predicted to be unstable have not experienced flow failure,

but this has not been regarded as casting doubt on the reliability of the method. As previously mentioned, the occurrence of a flow slide requires both a susceptible bank condition and hydraulic or other conditions that will trigger the mechanism. In most cases where banks have been predicted to be unstable but where flow slides have not occurred, it is thought that the severity of river attack has not been sufficient to initiate flow failure.

Techniques for channel-meander model

The initial objectives of the potamology program also included development of a model and model-operating technique that could be used to predict future changes within a specific river reach. The early meander model studies had been handicapped because of lack of knowledge of proper movable-bed materials. There was needed in particular a material that would both simulate the varying cohesiveness of prototype caving banks and serve as a true bedload material after caving into the stream, which material would then have little or no cohesion. Another requirement was that the movable-bed model should be able to move large quantities of bedload in relation to the amounts contributed by one or two local caving banks.

It was decided that the desired techniques could best be developed in a movable-bed model of a reach of the Mississippi River in which considerable bank recession and channel changes had occurred but which had not been complicated by construction of any manmade structures, such as revetments or dikes. Accordingly, the Concordia-Scrub Grass Bend reach was selected and was modeled to scales of 1:400 horizontally and 1:100 vertically. Crushed bituminous coal was used as the basic material for both the model and the banks, and a binding agent was mixed with the bank material for simulation of the cohesive properties. This phase of the overall potamology program was successful in that the model and model-operating techniques sought were developed.

Investigation of 110-volt echo sounder

Another potamology project was a special investigation to determine the ability of a 110-volt echo sounder then in use to locate revetments under water. An extensive and carefully controlled program of testing was undertaken and completed, using the typical echo sounder then used in the Districts of the Lower Mississippi Valley Division. The conclusions were that the instrument was extremely accurate and rapid as a hydrographic survey instrument. However, it was not able to distinguish between the natural bottom of the river and a revetment mattress. So far as the potamology investigations were concerned, then, the results of the investigation were negative in that it was demonstrated that the standard echo sounder could not be used to determine if revetment was still in place on the bottom of the river.

Potamology study program (1957-1961)

Although, as previously noted, the potamology program was essentially halted at the end of Fiscal Year 1951, some reports of studies begun prior to that time were subsequently completed. Early in 1957, there was established by the Mississippi River Commission a Potamology Board to formulate and direct a program of potamology investigations relating to stabilization of the lower Mississippi River. The membership comprised staff representatives from the office of the Mississippi River Commission, the Waterways Experiment Station, and the three Districts. During its 4-year activity, the Potamology Board resumed several investigations that had lapsed in 1952, and initiated others.

Rotary cone penetrometer

One of the continuing projects was that of making bank stability predictions, based on analyses of borings for revetment construction made in the three Districts. Another project was further development of the rotary cone penetrometer, initially devised after study authorization in 1949 to fill the need for a method of determining the penetration resistance of soils in deep borings for correlation with the physical characteristics of the material, thus providing information on areas susceptible to flow slides faster and more economically than by conventional borings.

In the early part of the revetment soils investigation, point-bar deposits were explored by means of 2-inch-diameter split barrel samplers. Efforts were made to obtain correlations between penetration resistance (the number of blows required to drive the sampler 1 foot) and the relative density of the sand. Reliable correlations were not obtained, and this method was replaced by undisturbed sampling with a thin-wall piston sampler. Although techniques were developed for obtaining undisturbed samples of sand with a thin-wall piston sampler and for measuring the density with a fair degree of accuracy, the procedure was time consuming and costly. It was also sometimes mechanically impossible to obtain continuous samples in an undisturbed sand-sample boring, and so it was possible that critical layers might be missed in the sampling procedure. Because of these drawbacks, a cone-sounding device was tested as a means of making continuous static soundings to a depth of 200 feet in sand deposits, using a truck-mounted rotary drilling rig. It consisted essentially of a 60-degree cone having a projected area of 1.55 square inches, with jet holes in its top to allow drilling fluid pumped through the drill rods to be forced out of the cone into the borehole in an upward direction. The cone was attached to a core-drill rod. The effects of friction developed by soil closing in on the rod above the cone as penetration progressed were found to limit penetration to a few feet, without some means of keeping the rod free of this effect. The solution was rotation of the cone concurrently with its penetration. A rotation speed of 25 revolutions per minute, a rate of penetration of 1 foot per minute, and a drilling fluid volume of 25 gallons per minute were determined to be suitable for operation in the various soils encountered. The equipment could be operated by means of a standard rotary drilling rig without interruption for reaming and casing the upper part of the hole. The new method was faster and more economical than other methods for deep static sounding. Figure 33 illustrates the device in operation.

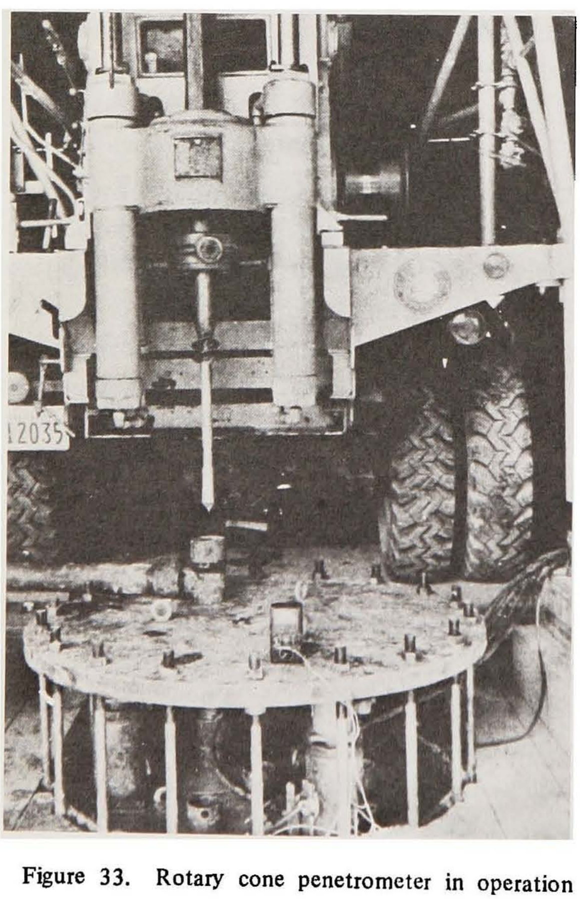


Figure 33. Rotary cone penetrometer in operation

The rotary cone penetrometer studies undertaken in 1957 were to improve the usefulness of the device and to determine the location of unstable sand deposits along the Mississippi River. These studies showed that cone thrust is a reliable measure of the combined effect of gradation and

density of sand being penetrated. Criteria based on cone thrust were developed for predicting the stability of revetment sites against flow failure. Also developed were techniques for routine use of cone-thrust data for prediction of the stability of point-bar riverbank deposits with regard to flow failure.

Although the cone penetrometer provides data that may be of value in determining the susceptibility to flow failure of point-bar sands at revetment sites, no flow failures have occurred to date at locations where cone penetrometer borings were made. Until the cone criteria can be verified by actual occurrence of flow failures, further studies are not warranted.

Hydraulic investigations

A study initiated by the Potamology Board in the period between 1957 and 1961 was a two-part hydraulic investigation. The first part was conducted by the Vicksburg District and consisted of making periodic revetment cross sections to determine changes in the elevation of the river bottom at the toe of the revetted bank, and also to determine what hydraulic conditions exist that might trigger a flow slide. The second part of the investigation involved observations of slope and flow patterns near Wrights Point (which were made by the Memphis District) and in the reach from Yellow Bend to the Greenville Bridge (which were made by the Vicksburg District).

Subaqueous seismic refraction and sonar pinger investigations

In addition, two investigations were begun to develop an instrument that could be used to determine the emplacement of revetment on the river bottom. One investigation involves the making of subaqueous seismic refraction surveys, and has been undertaken by the Vicksburg District (see figure 34). The other involves a study by the New Orleans District of a device termed the "sonar pinger," the manufacturer of which claimed it would be able to distinguish between revetted and unrevetted banks.

Figure 34. Subaqueous seismic refraction test

Potamology study program (1963-1972)

Potamology research was again virtually at a standstill from 1961 to 1963. The Board was reestablished in May 1963 for the purpose of serving as a board of consultants to the President of the Mississippi River Commission to recommend "a program of potamology investigations relating to the stabilization of the lower Mississippi River, including specific areas or items to be investigated; District or Districts recommended for the tasks; and, when practical, target dates for accomplishment." The Board was also assigned the review of and reporting on the effectiveness of assigned investigations. The Board comprised representatives of the same offices as constituted in 1957, with the addition of a member from the St. Louis District. Potamology research projects include the following:

a. Field work and analysis of revetment cross sections to determine the relation between changes in stages and bed elevations along revetments, and effects of these changes on bank stability.

b. A continuing investigation to determine the validity of an empirical method of predicting susceptibility of banks of alluvial rivers to flow slides (liquefaction-type failures).

c. Field verification of the accuracy of the rotary cone penetrometer as a device designed to provide information on areas susceptible to flow slides faster and more economically than by conventional borings.

d. Field verification of the seismic method of locating mattress.

e. Contract with a commercial concern for design and development of the sonar pinger to locate revetments under sand and silt.

f. Examination of underwater concrete mattress by divers to ascertain the condition of the lap of new revetment for comparison with design lap, condition of lap after deepening of the channel, and condition of lap on steep underwater slopes.

g. Office feasibility study of methods of preventing flow slides in areas predicted as being unstable by the empirical method.

h. Model study of factors affecting the performance of dike systems in alluvial streams, including permeability, shape and elevation of crest, angle of dikes to normal streamflow, spacing between dikes, and change in sediment load.

i. Field and office study of dike systems, including a review of experiences with contraction works, an investigation of existing dike systems, and planning and testing of new structures.

j. Hydraulic analysis of Mississippi River channels to include office and field studies to develop criteria for curvature of bends; the length, width, and depth of crossings; and alignment of relatively straight reaches.

k. Construction of experimental test sections to explore the feasibility of substituting a plastic filter cloth for the gravel blanket beneath the upper bank paving.

l. Construction of experimental test section to explore the feasibility of using a plastic filter cloth under revetment mattress to prevent leaching of material through the revetment openings.

m. Laboratory investigation to study the feasibility of eliminating shoaling in harbor entrances.

n. Experimental test sections to explore the feasibility of using sandbags as a construction material in foreshore dikes.

Committee on Channel Stabilization

Closely related to the project investigation and research activities of the Mississippi River Commission are the functions of the Corps-wide Committee on Channel Stabilization, established in 1962 by the Chief of Engineers. The broad purposes of this committee are to keep abreast of current channel stabilization planning and construction and the problems arising therefrom; to serve as an advisory body to Divisions and Districts; and to encourage research in problem areas. The group is chaired by a member of the Office, Chief of Engineers, and includes members from Division and District offices involved in

major stabilization problems, and a representative from the Waterways Experiment Station. At sessions held in various parts of the country three times a year, the committee inspects local channel stabilization works of particular interest, and convenes for presentation and discussion of papers on stabilization problems and planning of future activities. As of 1972, the program adopted by the committee includes assembly and publication of information on channel stabilization problems and sponsoring of laboratory research.

Potamology Research Branch in Mississippi River Commission office

In January 1963, a Potamology Research Branch was established in the Engineering Division of the Mississippi River Commission office. The chief of this branch is responsible for coordinating the studies recommended by the Potamology Board and approved by the President, Mississippi River Commission. He is assigned the conduct of engineering investigations, research, and development in all fields of potamology needed to establish authoritative guides for design and construction of future channel rectification and stabilization works supervised by the Commission office. Close coordination with the Potamology Board is assured by designating the branch chief as a member of the Board and as its secretary.

Since establishment of the Potamology Research Branch and reactivation of the Potamology Board in 1963, 15 research projects have been completed or are underway. These projects are divided into two basic problem or study areas. The first of these is concerned with bank stability and alignment, and the second with improvement of the low water navigation channel.

One of the major problems in the bank stabilization program is the identification of banks susceptible to failure by flow slides. This particular problem has been solved through the development by the Waterways Experiment Station of an empirical formula that can be used to predict, with a reasonable degree of accuracy, the areas likely to develop a flow failure. However, now that the suspect area can be identified, the question arises as to what can be done about it. A feasibility study of this problem was made by the Waterways Experiment Station. It was found that there are several possible methods of stabilizing a potentially unstable bank. A 5-year program of field and laboratory experiments to test the proposed methods is underway.

Major research effort in connection with improvement of the low water navigation channel is directed toward determination of the optimum design of contraction works. This research is being accomplished by a hydraulic model investigation designed to evaluate such dike parameters as height, length, spacing, angle to flow, and configuration of crest. The dike designs showing the most promise in the model are being used as the basis for the design of the dike systems now being built in the Mississippi River. These prototype systems are being carefully observed to determine performance in comparison with the model results.

The research program is directly related to the channel improvement program in that all phases of the research program are directed toward obtaining results having positive and realistic application in advancing the improvement program and achieving economics in construction practices, materials, and future maintenance. In addition to meeting the needs of the current work program, consideration is being given in the design of the channel structures to provide for future modifications meeting possible requirements for a somewhat deeper navigation channel.

District Revetment Study Boards

Although means of increasing the efficiency and economy of articulated concrete revetment

operations have been continually sought, a formal program was initiated in June 1964 with the designation of Revetment Study Boards in the Vicksburg and Memphis Districts. These two offices have had the responsibility for a number of years of placing all articulated revetment mattress in the three Districts. Personnel assigned to the Study Boards served on a full-time basis in order to assure time and opportunity to explore and develop new ideas and methods. The Boards were given broad latitude to carry out their mission. They were authorized to initiate contracts with private concerns to make studies and to perform research and tests.

Several such contracts were made soon after designation of the Study Boards. One concerned study and evaluation of transfer of articulated concrete mattress from the casting field to the transport barge; another involved an analysis of articulated concrete mattress assembly operations; and a third was an equipment maintenance and management study of revetment operations. A fourth study was aimed at developing an improved mat-laying system or of revising the existing system. Based on studies made under the contracts involving bank protection problems and analysis of current construction methods and procedures, and on in-house reviews, it appeared that improvements to the existing system offered the greatest potentials for savings in cost and improvement in construction procedures, including eventual reduction in labor requirements on the two sinking plants. The contract studies confirmed earlier conclusions regarding feasible areas for improved procedures and new equipment affecting the revetment plants. These included, first, an improved means of moving the revetment squares from the transport barge to the fabricating deck that would be both faster and safer than by the old whirley cranes then in use on the Memphis District plant; second, development and construction of a two-square pickup frame to replace the old monosquare pickup frame; and third, development of power-operated tying tools to replace the hand-operated tying tools. Concurrently with the studies made under these consultant contracts, the in-house Study Boards made detailed investigations of virtually every phase of the operations involved in manufacturing and placing the revetment. All of these were completed when the Study Boards were discontinued in July 1968. Illustrative of studies conducted by the Study Boards are the following items:

a. Increasing the efficiency of overbank clearing operations through use of equipment of improved design, including reduction of clearing width. A reduction on the order of 40 to 50 feet was accomplished.

b. Developing a device to save a substantial quantity of launching strand lost under present practices because the strand required to lower the last launch of mat to the river bottom cannot be retrieved. This study did not achieve the hoped-for result.

c. Developing procedures to reduce the time required to exchange transport barges at the mat boat and transfer the mattress sections from transport barge to the fabricating deck. A degree of success resulted from this study.

d. Continuing studies initiated in the Memphis District in 1930 of means for automatic and semiautomatic fastening of the mattress section. After testing several types of ties and tools for their placement, a design for an automatic tool was adopted (see figure 35). Such tools were in use on the Memphis District sinking plant in the Fiscal Year 1971 construction season and made possible a substantial reduction in mat-boat personnel.

e. Reducing the need for pocket mats, used to cover areas where the main-river mat could not reach the waterline. These pocket mats are costly and their placement is time consuming. Use of a "mat puller" device on the Vicksburg District sinking plant has eliminated the requirement for pocket mats.

f. Automating winches on mooring barges to give better control to the deck foreman by allowing one or two men to control all winches from a convenient station. Such a system was adopted for use on the Memphis District's sinking plant.

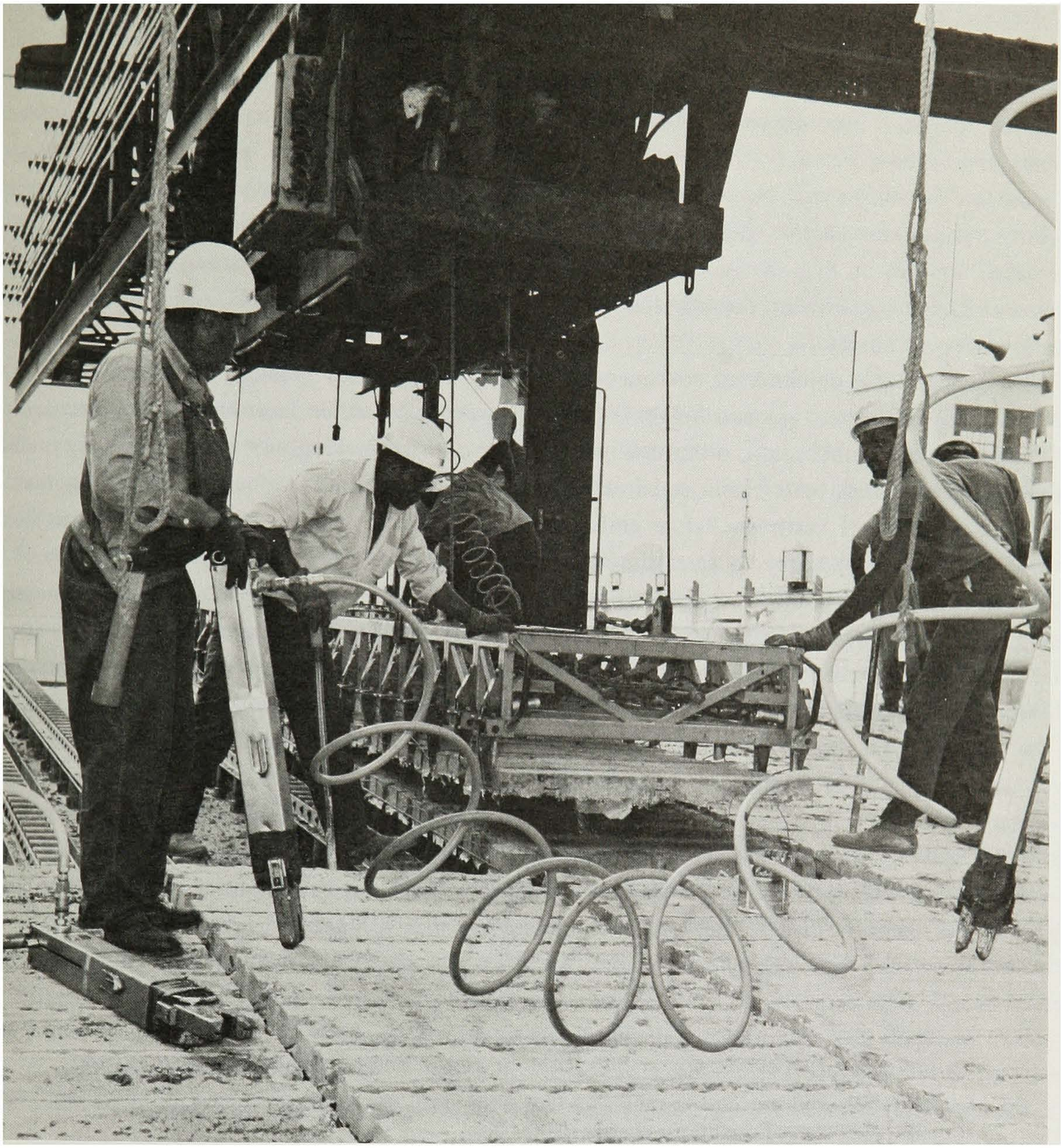


Figure 35. Mat-tying device, mat-lifting frame, and reciprocating carrier

Largely as a result of the contract study for the development of an improved mat-laying system, the Memphis District sinking plant was rebuilt with a wider mat-assembly deck and four overhead-supported gantries, each using two-square mat-lifting frames.

The Vicksburg District sinking plant has used two-square frames for several years. This plant has also been changed to use tying tools.

It is pertinent to note that the contractors utilized by the Study Boards did not succeed in developing innovations in procedures or equipment, although one organization was highly effective in developing improved equipment based on ideas which were in-house originated.

Feasibility study of improved methods for riverbank stabilization

Despite steadily increasing labor and material costs since World War II, improvements in the production and placement of articulated concrete mattress have made it possible to hold down the cost of this revetment. Even though further improvements in design and construction procedures have been constantly sought, it has long been evident that the limit for major improvement in this type of protection is being approached. However, this revetment does have certain drawbacks. It is costly to construct and to maintain. Placement can be done effectively only during the low water season, thus restricting use of costly one-purpose plant to a few months each year. There must be much dependence on river alignment and depth, and when they are not suitable, construction of a bendway in stages frequently becomes necessary. Loss of revetment through flanking may result, as well as offsets in alignment and a lack of uniformity in curvature.

The considerable amounts of revetment remaining to be placed between Cairo and Baton Rouge and the newly authorized portion below Baton Rouge provided ample incentive to seek new concepts for design of bank stabilization, using new materials or perhaps making new uses of existing materials, with the objective that better bank stabilization might be achieved at an equal or lower cost than that of articulated concrete mattress. Before embarking on a research program of this type, it was decided to conduct a feasibility study to ascertain if any new material had been developed or appeared to have a potential of being developed for application to bank stabilization work. Since neither the Commission staff nor the Waterways Experiment Station staff had the capability to make such a study, the determination was made that a contract with a private consulting organization would be negotiated for this work. It was particularly desired that the private firm be familiar with developments in such fields as the chemical and plastic industries and have the capability to relate the findings of research to the revetment problem. The findings of the feasibility study would include recommendations as to detailed investigations deemed to have the greatest likelihood of success. In order to utilize advantageously the knowledge and experience gained from other research in the general field, it was arranged for the contract to be negotiated and supervised by the Waterways Experiment Station. A contract with a firm of consulting engineers was made in June 1963, and the final report was submitted in November 1964.

Describing the work done under this contract, the report stated that the major investigations included studies of the following:

a. Materials that are either available now or might be available in the foreseeable future which could be used in riverbank stabilization or other related river control structures.

b. Construction and placement methods that have been used, are now used, or could be developed for the purpose of installing bank protection.

c. The interdependence of fluvial hydraulics and bank channel stabilization, and of the criteria that should be satisfied by effective bank protection.

In addition to the technical disciplines normally associated with civil engineering and construction, investigations were included in the fields of chemistry (chemical soil stabilizers, polymeric chemistry, and asphalt chemistry) and physics (electrokinetics and thermodynamics). The primary sources of information were available literature, and conferences and other communications with industry, educational institutions, and trade associations. The investigations were primarily directed toward determining the technical feasibility of utilizing different materials and methods. The purpose was to determine whether any of the recent developments in the various technical fields could be used effectively and economically.

The report did not disclose any radically new or better means of bank stabilization than those

in current use, but found that existing methods are generally satisfactory. Included with a detailed statement of conclusions and recommendations was the observation that a better understanding of the functioning of the present protective system is essential to any successful effort to reduce the cost of riverbed protection. Accordingly, it recommended that an extensive effort be made to integrate existing knowledge of the mechanics of flow in open channels, hydrology, geomorphology, soil mechanics, and related fields as they apply to river control structures. It further concluded that it is essential to initiate a study of the variation of flow phenomena with stage, and that research is needed to establish the magnitude of roughness elements required for control of large rivers. It concluded that further effort should be exerted to improve modeling techniques, and that greater use should be made of large scale models in conjunction with actual river work. With respect to types of artificial riprap for upper bank protection, the report commented that the production of soil-cement blocks, asphalt-stabilized soil blocks, crude glass stones, and possibly ceramic riprap by the pyroplastic method has the greatest potential for replacing quarried stone, and that the production of crude glass riprap (melting sand) appears to be technically feasible. Synthetic elastomer sheeting, the report noted, appears to be economical when considering in-place cost, but should be further investigated to determine its economy, including maintenance cost.

Careful consideration was given to all report recommendations. It was agreed that more model research and field investigations are needed to establish improvements in model techniques, design criteria, and existing protection methods for bank stabilization. Action was taken to expand the scope of the potamology research program to include suggested model studies or to undertake new ones, and to make proposed prototype investigations. Suggested researches involving materials or processes of excessive current cost or of uncertain technical feasibility were deferred.

Role of the Waterways Experiment Station

In his report of 1 December 1927, which set forth the engineering plan later adopted by the Flood Control Act of 1928, General Jadwin, Chief of Engineers, discussed "the establishment of a hydraulic laboratory similar in some respects to such research organizations carried on by certain European governments." The report expressed the view that, although actual experience with full-size structures is preferable to experimentation with small-scale models, on occasion questions relative to the flow of water could be worked out by small-scale experiments, and that such experiments might be useful in some of the lock and dam designs. In addition to experiments, the hydraulic laboratory organization might well be charged with the coordination of field data relative to the flow of the Mississippi and other rivers. It could take charge of discharge measurements, silt measurements, slope and velocity measurements, and the like, making studies and drawing conclusions therefrom. The laboratory could be a clearinghouse for such data, and could publish them. General Jadwin recommended that the Corps of Engineers be authorized to establish a hydraulic laboratory, the cost of its operation and of publication of scientific data to be funded out of the annual rivers and harbors and flood control appropriations.

For a number of years prior to passage of the 1928 Flood Control Act, establishment of a national hydraulic laboratory had been advocated by prominent members of the civil engineering profession. In September 1922, a hearing was held by a subcommittee of the Senate Committee on Commerce on Senate Joint Resolution 209, 67th Congress, 2d session. This resolution proposed that a national hydraulic laboratory be established in the District of Columbia, in connection with such bureau as the President might designate, for the conduct of research, experiments, and scientific studies in connection with the problems of river hydraulics, and proposed that an appropriation of $200,000 be authorized for the

purpose. Detailed testimony was given by Mr. John R. Freeman, a consulting engineer who at that time was president of the American Society of Civil Engineers. In developing the need for this facility, Mr. Freeman contrasted the large expenditures made on improvement of the lower Mississippi and Missouri Rivers with the lack of progress in stopping bank caving and channel shifting. He presented sketch plans for the laboratory facilities to be housed in a one-story building about 73 feet wide and 385 feet long. To illustrate what could be done with such a facility, he furnished a list of 64 studies concerning the river and other problems that could be made in the laboratory. With one exception, other persons testifying at this hearing supported the resolution. The sole exception was Mr. John A. Ockerson, a member of the Mississippi River Commission and a past president of the American Society of Civil Engineers. Representing the Mississippi River Commission, Mr. Ockerson opposed establishment of the laboratory on the grounds that it would be wholly impracticable to obtain any further useful data regarding the Mississippi River problems by the use of laboratory models. In using the term "models," he referred to the whole scheme of hydraulic laboratory work.

Further hearings were held in June 1923 and May 1924 on the joint resolution and were generally favorable to the idea of a hydraulic laboratory. Although the bill was favorably reported, no action was taken.

At a symposium entitled *The River and Harbor Problems of the Lower Mississippi*, sponsored by the American Society of Civil Engineers and held in New Orleans in April 1923, Mr. Freeman presented a paper entitled *The Need of a National Hydraulic Laboratory for the Solution of River Problems.* The paper was a more detailed presentation of his views than was given in the testimony before the Senate subcommittee. In it, he asserted that the purposes of the laboratory were the promotion of economy and expenditures for flood control and navigation and advancing the ultimate attainment of a much desired channel from St. Louis to the sea. He favored establishment of the laboratory in Washington rather than at some point in the Mississippi Valley because he believed that for best results it should be in a scientific atmosphere; and moreover, at that location it could be useful to other departments of the Federal Government.

Establishment of a national hydraulic laboratory to be located in the Bureau of Standards in Washington was envisioned by S 1710, introduced in the first session of the 70th Congress. This bill was amended by the Senate to include creation of a National Hydraulic Laboratory Board, the three members of which would be the Secretaries of Commerce, War, and Interior, and whose duties would be to determine a program of projects to be undertaken and the manner of performing the work. As amended, the bill was passed by the Senate. Hearings by the House Committee on Rivers and Harbors, held on 26 and 27 April 1928, showed that the proposal was supported by various professional engineering groups. At a hearing held on 15 May 1928, note was taken of the passage by the Congress of the Flood Control Act of 1928 which, when approved, would give specific authority to the Chief of Engineers to establish a hydraulic laboratory. At this hearing, General Jadwin attached great importance to location of the laboratory along the lower Mississippi River and indicated that he had under consideration several possible sites below Memphis. As a result of General Jadwin's testimony, action toward establishment of a National Hydraulic Laboratory was deferred by the House Committee.

The engineering plan approved by the Flood Control Act of 1928 included a fixed spillway at Bonnet Carré. The first hydraulic model study to be made subsequent to passage of the 1928 act was begun late in 1928 as a part of a program of field investigations at the site. A hydraulic model was constructed and tests were conducted to determine the coefficients of discharge of the weirs, velocities and scour in the stilling basin, the effectiveness of various materials in protecting against scour, backwater

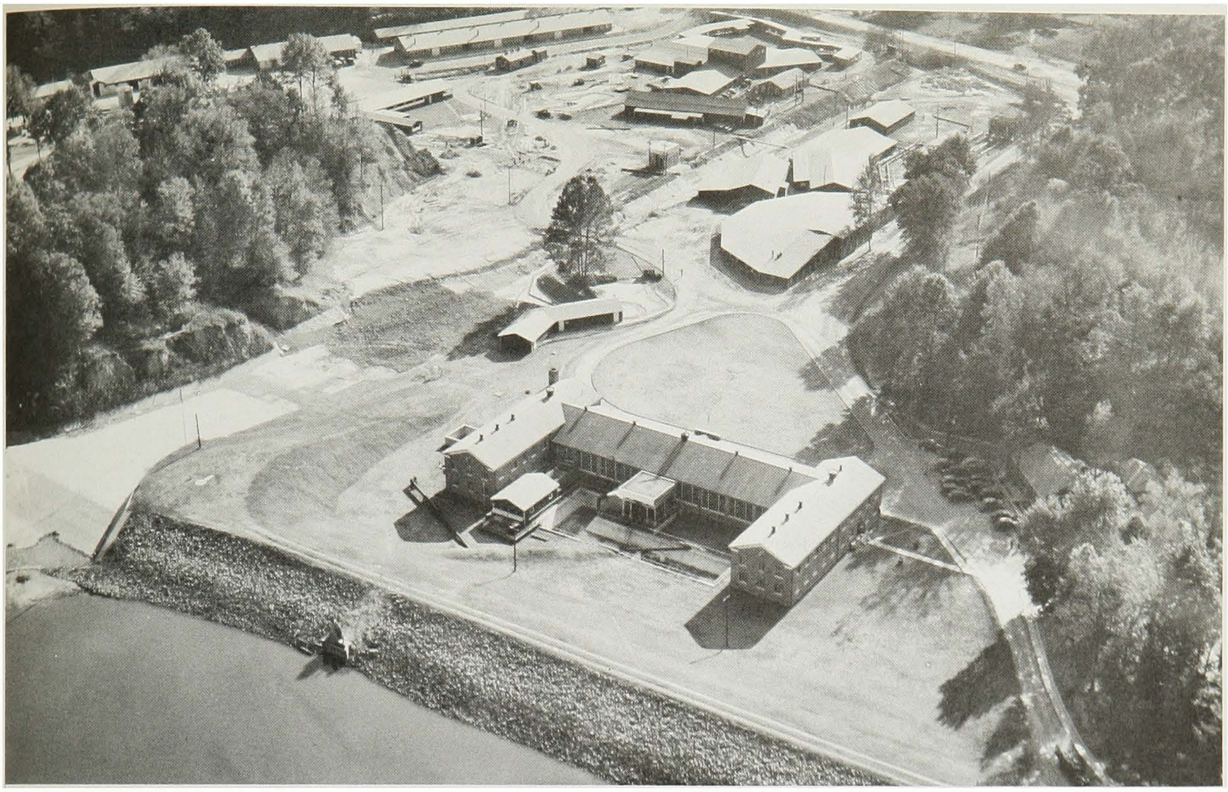


Figure 36. General view of the Waterways Experiment Station in the early 1930's

curves for the spillway proper, and scouring and deposition velocities for spillway soils. By letter dated 18 June 1929, based on the authority contained in the Flood Control Act of 15 May 1928, the Chief of Engineers directed the President of the Mississippi River Commission to establish a hydraulic laboratory. Plans to locate the Waterways Experiment Station in the vicinity of Memphis, Tennessee, were made in the summer of 1929. However, by December of that year, it had been decided to build the station at Vicksburg, Mississippi (see figure 36). A career officer of the Corps of Engineers, Lt. Herbert D. Vogel, was assigned as Director of the new facility, which was under the direct control of the President of the Mississippi River Commission.

Initially, the Waterways Experiment Station was concerned with construction and testing of scale models of features of the adopted project (see figure 37). One such model was that of the Mississippi from Helena, Arkansas, to Donaldsonville, Louisiana, a river distance of about 490 miles. The model included the Atchafalaya Basin and backwater areas below Helena, and was constructed to scales of 1 to 2,000 horizontally and 1 to 100 vertically. It has been used to check levee grades; to determine the effects of floodway operations, including the operation of the proposed Eudora Floodway which was eliminated from the project, and the Atchafalaya Basin Floodways which have been essentially completed but not yet operated; and to determine the effect of such other flood control measures as levee extensions and dikes. A recent use has been to determine the effects of improving the main channel through the Atchafalaya Basin and of closing distributary channels off the main channel. A model to the same scale was constructed of the Mississippi River from Tiptonville, Tennessee, to Thebes, Illinois, above Cairo, including a portion of the lower Ohio River and the Birds Point-New Madrid Floodway. It was used for tests of operation of the floodway, for checking levee grades, and for determining the effect of other flood control measures.

Figure 37. First model at the Waterways Experiment Station: Determination of Mississippi River backwater limits on Illinois River above Grafton, Illinois

Large-scale movable-bed models, using sand, coal, or plastic bed materials, have been used for problems involving caving banks and channel changes, such as Memphis Harbor (figure 38), Reid-Bedford Bend (figure 39), and the Greenville reach (figure 40). Models have also been used to study sediment diversion and shoaling. The general study of the meandering of alluvial rivers, described previously under "Channel Stabilization Investigations," was also made by a movable-bed model. A sand-bed model is now being used in studies of dike systems. A large-scale fixed-bed model, used in the study of a cutoff across Slough Landing Neck near Bessie, Tennessee, simulated the area from near Columbus, Kentucky, to Tiptonville, Tennessee. It aided in estimating the stage lowering that would result from the cutoff, and the possible effects on navigation. Models of hydraulic structures to large scales have been used to aid in the design of diversion structures, spillways, and outlet structures for dams, stilling basins, and navigation locks and dams.

A comprehensive model of the Mississippi Basin was authorized in 1942, primarily to study the effect of tributary reservoir regulation on Mississippi River floods. The model was later used in investigations for planning, design, and coordinated operation of all flood control works in the basin. Although construction of the model was not completed until 1966, specific reaches were used as soon as they were completed for flood control investigations, including a study of additional protection for the Birds Point-New Madrid Floodway. The model, located near Jackson, Mississippi, is constructed to the same scales as the Helena to Donaldsonville model, and includes the Missouri River below Sioux City; the Mississippi River from Hannibal to Baton Rouge; the Ohio River below Louisville, including portions of the Wabash, Cumberland, and Tennessee Rivers; the Arkansas River below Keystone Dam;

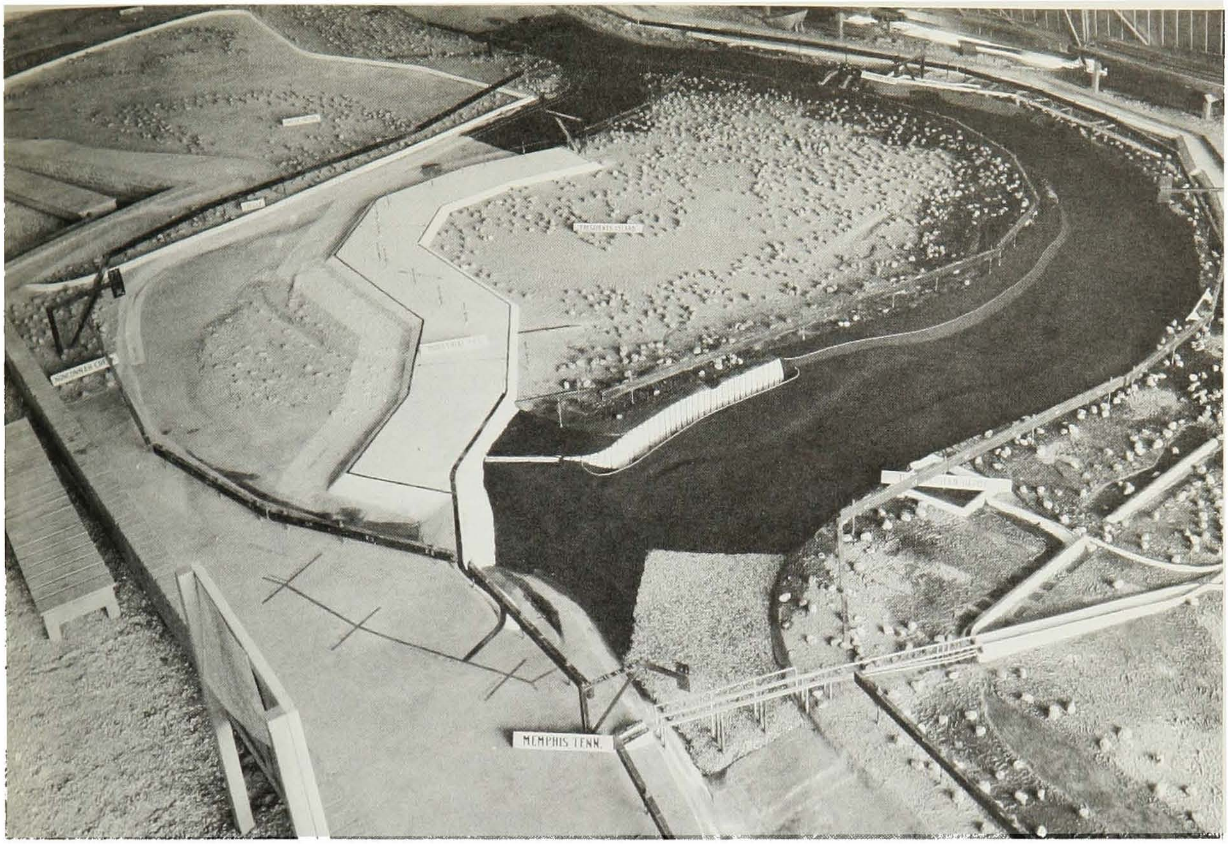


Figure 38. Model study of Tennessee Chute closure and industrial fill for Memphis Harbor

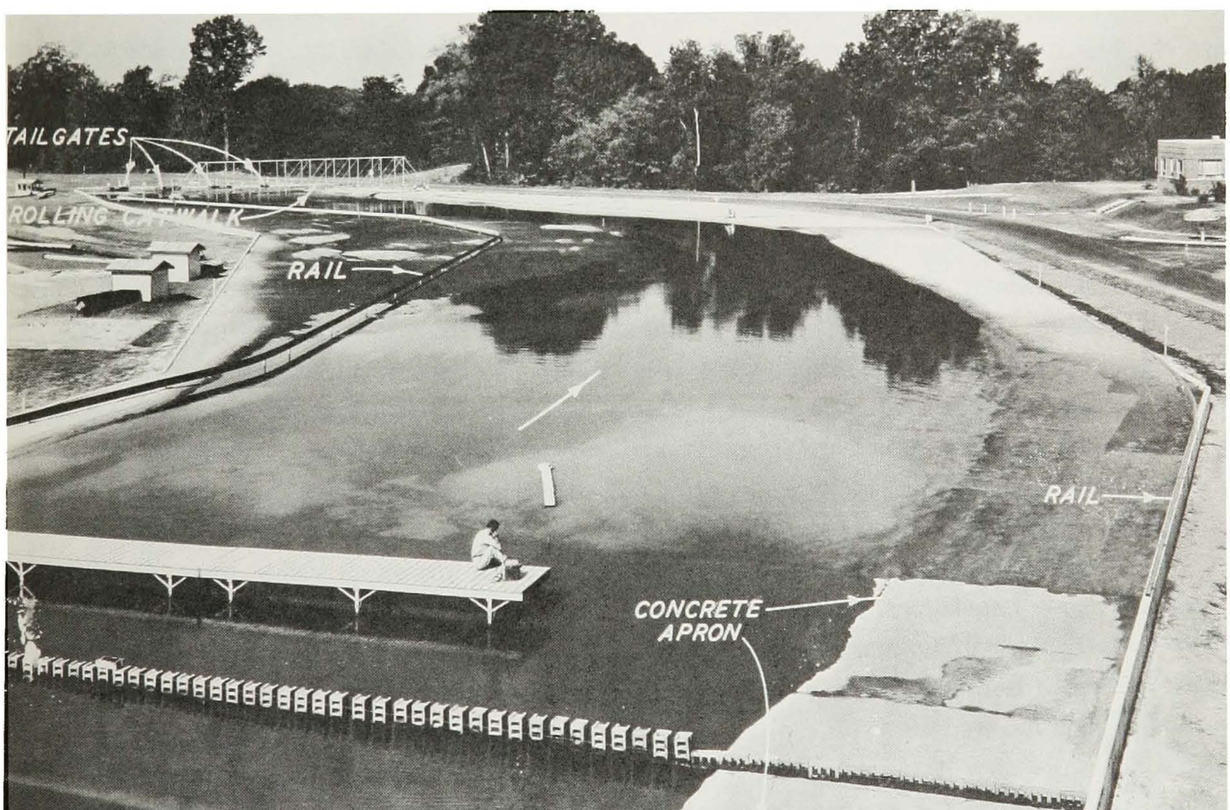


Figure 39. Model study of Reid-Bedford Bend, Mississippi-Louisiana

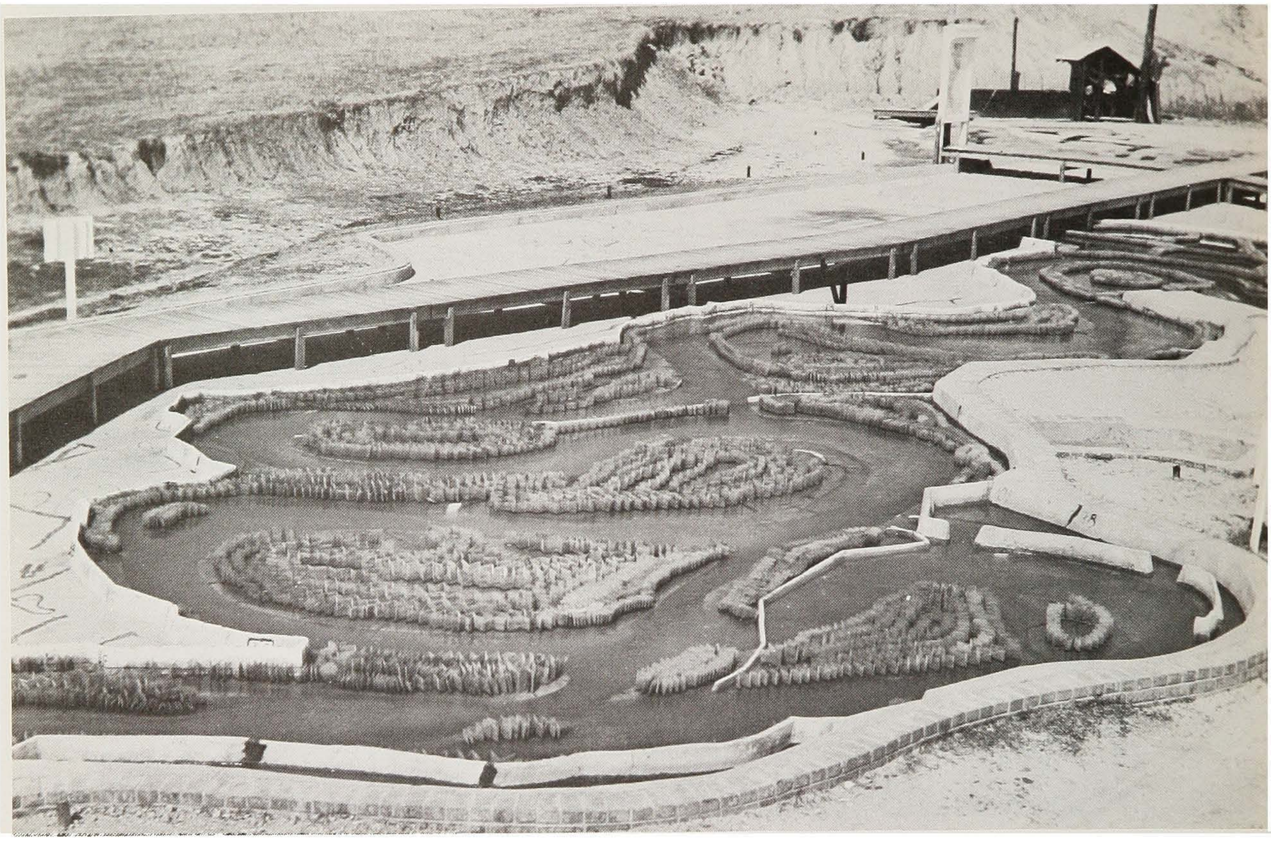


Figure 40. Model study of Greenville Bends, Mississippi

and the Red River below Alexandria (figures 41 and 42). It includes, also, the floodways and backwater areas along the Mississippi and the Atchafalaya Rivers. The Thebes to Tiptonville model at Vicksburg was abandoned when the area was included in the completed portion of the Mississippi Basin model; likewise, the Helena to Donaldsonville model was abandoned for testing purposes upon completion of that reach in the Mississippi Basin model.

The Depression of the 1930's and the resulting unemployment gave impetus to an enlarged program of civil works assigned to the Corps of Engineers. In consequence, a need arose for hydraulic model studies of diverse types required by other Corps of Engineers Districts in addition to those under the direction of the President, Mississippi River Commission. The Experiment Station gradually developed into a Corps-wide facility that was available to assist all Districts with design and construction problems by conducting hydraulic model tests of spillways and outlet works for dams; breakwater systems for harbors; filling and emptying systems for locks; and navigation improvements, such as dredging, jetties, and dikes for rivers and estuaries.

Also, in this period, the construction of levees in the lower Mississippi Valley, some to considerable heights on poor foundations, created a need for a laboratory to analyze the local soils and determine their potential strength as foundations or as materials of construction. The result was establishment of a soil mechanics laboratory as an additional aid to the design engineer. As in the case of the hydraulic laboratory, this facility soon expanded the scope of its operations to render a Corps-wide service, assisting Districts in the design of adequate earth foundations and stable earth structures and excavations. Besides performing tests normally required for engineering investigations and design and acceptance tests, the

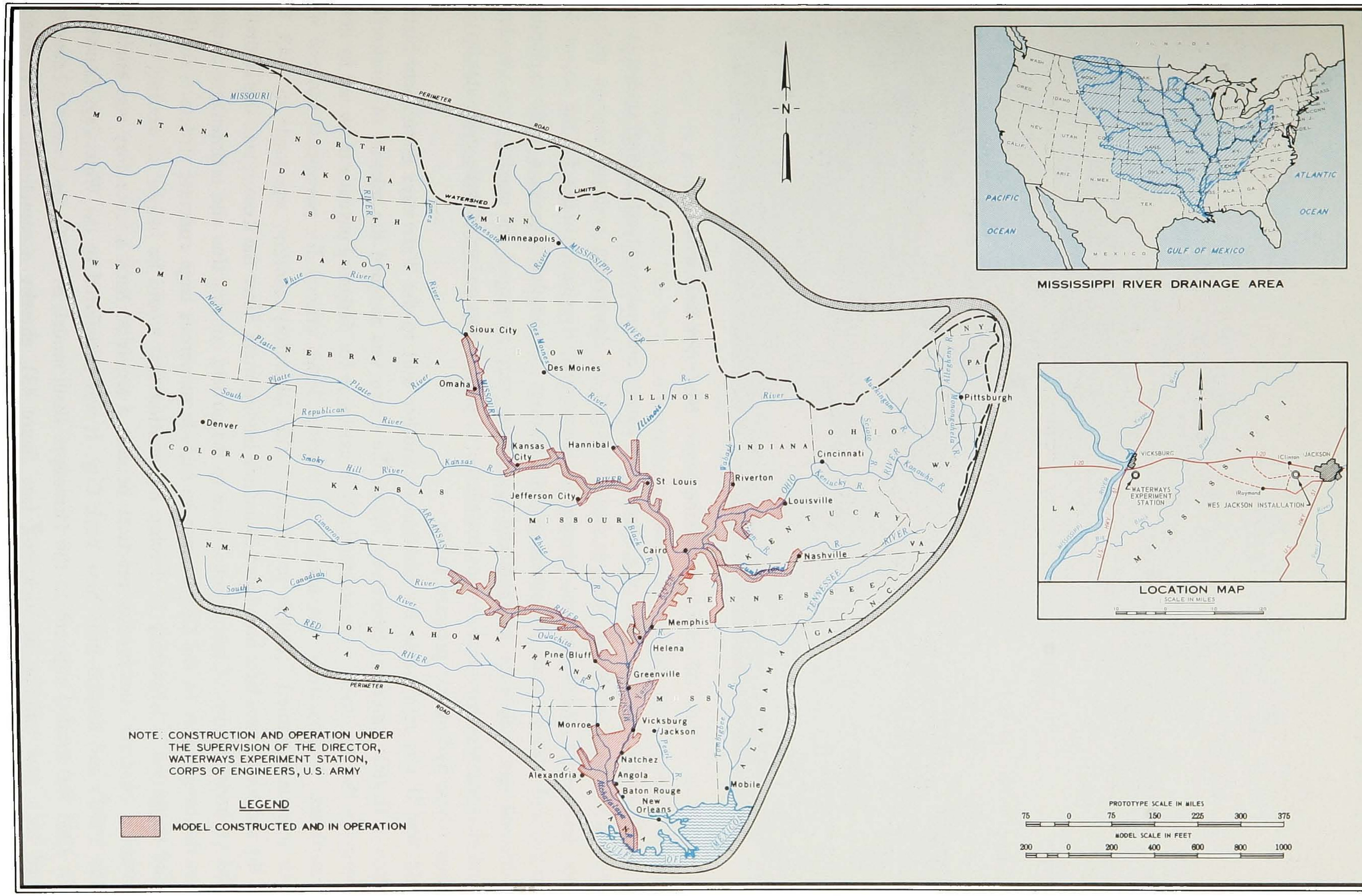


Figure 41. Prototype area reproduced in comprehensive Mississippi Basin model

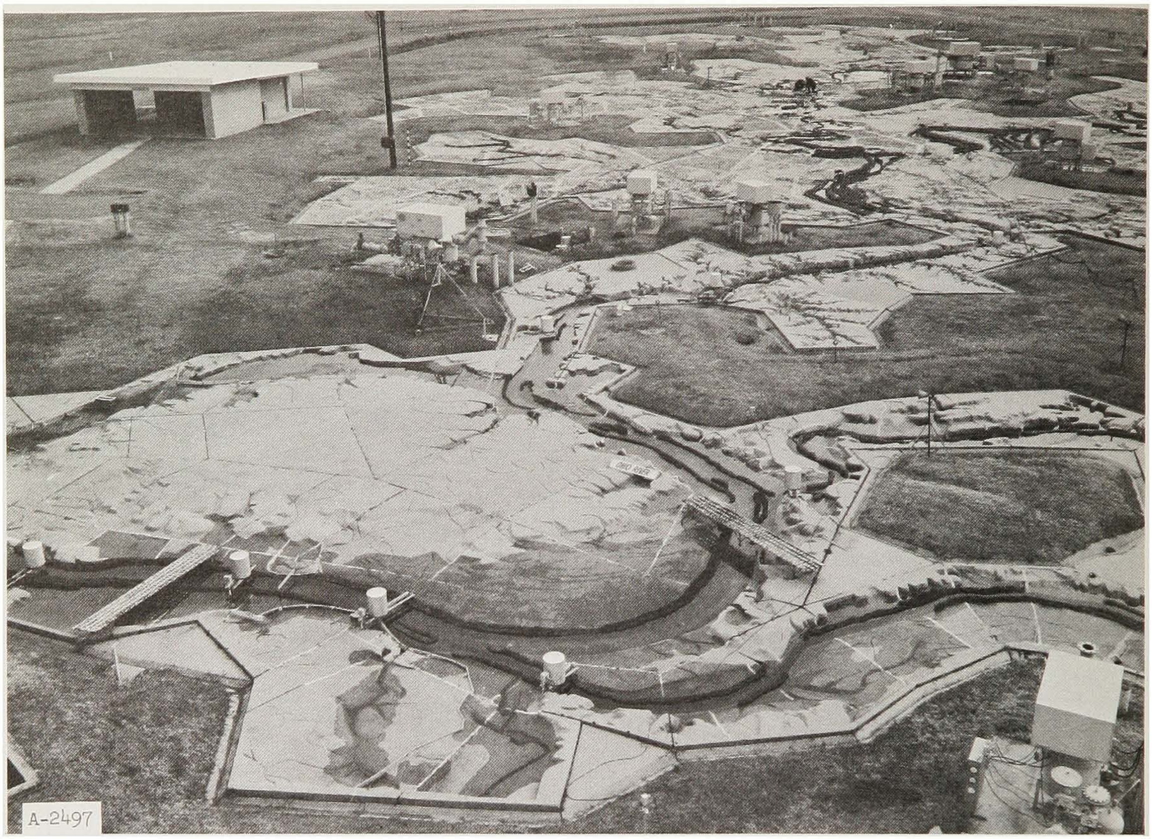


Figure 42. Portion of comprehensive Mississippi Basin model

laboratory soon was undertaking tests of a nonroutine nature and making investigational studies in soils and related fields. The workload grew to include design of dewatering systems, seepage analyses, pile-loading tests, earth and hydrostatic pressure measurements, riverbank studies for the potamology investigations, and analyses and evaluations of soils features of completed projects. Field exploration facilities for soil and rock were acquired, and capabilities were developed for making cone soundings, seismic and electrical resistivity explorations, installation of piezometers and relief wells, overwater borings, and borings where hydrostatic pressure exists.

World War II was responsible for addition of another unit to the Waterways Experiment Station organization—a flexible pavement laboratory. When the Corps was assigned the mission of constructing airfields early in the war, there were no standards in existence for designing pavements for use by heavy military airplanes. A laboratory was needed to develop design criteria for pavements surfaced with bituminous materials, termed "flexible pavements." This laboratory addition was made in 1943. The scope of the assignment was later broadened to include landing mats. Since the Korean war, this laboratory has carried on investigations of major importance to the airfield construction and maintenance program.

When the assignments to the Corps began to include numerous large concrete structures for flood control and navigation, a laboratory to develop information that would be helpful in assuring efficient and economical concrete construction practices became a requisite. Such a laboratory was established late in the 1930's and located near New York City. It was transferred to the Waterways Experiment Station in 1946 and located adjacent to the Mississippi Basin model. In 1969, the Concrete Laboratory was moved to a new building in Vicksburg (see figure 43), thereby accomplishing an economical

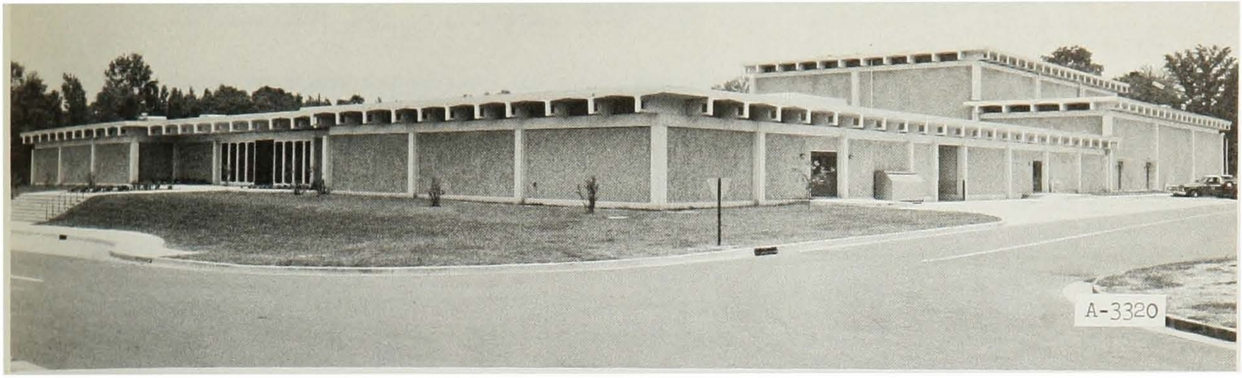


Figure 43. Concrete Laboratory, Waterways Experiment Station

consolidation of the major investigational facilities of the Corps. In addition to basic and applied research in concrete, this laboratory tests construction materials, such as riprap, concrete aggregates, and rubber water stops; performs acceptance testing to determine if materials comply with specifications; designs concrete mixtures and evaluates those designs when construction begins; and furnishes guidance on control during construction.

Because of the nationwide, and even worldwide, scope of its activities, direct control of the Waterways Experiment Station was shifted in 1949 from the President, Mississippi River Commission, to the Chief of Engineers. It is today the principal laboratory facility for the Corps of Engineers and is engaged in research and engineering investigations in the fields of hydraulics, ecology, concrete, soil mechanics, mobility of military vehicles, nuclear weapons effects, and flexible pavement design. It serves all offices of the Corps on a reimbursement basis, and its capabilities are available on the same basis to other Federal and defense agencies. The Soils and Pavements Laboratory provides soil laboratory testing services and conducts geological studies for the Mississippi River Commission and Lower Mississippi Valley Division. Similarly, the Concrete Laboratory functions as the materials and concrete laboratory for the Commission. On request, both technical laboratories conduct training courses for construction inspectors of the four Districts of the Lower Mississippi Valley Division to insure that appropriate methods and procedures are employed in control testing and construction inspection. Figure 44 is an aerial view of the Waterways Experiment Station at Vicksburg in 1972.

Figure 44. Aerial view of Waterways Experiment Station, 1972

CHAPTER IV. PROJECT DESIGN AND CONSTRUCTION

Levees

The main-stem levees on the west bank of the Mississippi River begin just south of Cape Girardeau, Missouri, and, except for gaps where tributaries enter the river, extend continuously to Venice, Louisiana, about 10 miles above the Head of Passes. The east-bank levees are not continuous because there are high bluff lines near the riverbank, making levees unnecessary. They extend intermittently from near Hickman, Kentucky, to a point above Vicksburg. Resuming at Baton Rouge, the east-bank levee extends continuously to Pointe a la Hache relief outlet near Bohemia, Louisiana, about 44 miles above the Head of Passes. Included in the main-stem levee system are the levees and floodwalls protecting Cairo and vicinity. The south-bank Arkansas River levee begins at Pine Bluff, Arkansas, and extends 85.4 miles along the south bank to join the west-bank levee of the Mississippi River 12 miles above Arkansas City, Arkansas. With the west-bank main-stem levee, it forms a continuous line of defense for the Tensas Basin to the south. The south-bank Red River levee extends about 60 miles from Hotwells to Moncla, Louisiana, and along with the West Atchafalaya Basin protection levee, shields a large area west of the protection levee from flooding. Both of these levees are considered to be a part of the main-stem levee system.

At the end of Fiscal Year 1931, 589 miles of main-stem levees had been completed to the 1928 grade and section. This figure includes levees on the south banks of the Arkansas and Red Rivers. It also includes about 13 miles of levee on the north side of the Arkansas River which had been constructed under the provisions of section 6 of the 1928 act, under which project funds could be expended for works previously authorized but not included in the new project, subject to special conditions of local cooperation. Also completed to 1928 grade and section were the 27.5 miles of Orleans Parish, Louisiana, levees which were not initially included in the project, but were incorporated therein by the Flood Control Act of 1950. The mileage of main-stem levees completed in 1931 to 1928 grade and section comprised about 35-1/2 percent of the 1,654 miles in the system.

At the end of Fiscal Year 1931, 123.5 miles of right-bank river levee had been built to 1928 grade and section in the Atchafalaya Basin. On the left bank, 53 miles had been built, but raising and enlarging to the 1928 grade and section were not authorized until passage of the act of 15 June 1936. Although rights-of-way for the basin protection levees were being acquired in 1931, a start on construction had not been made.

Prior to 1932, no Federal levee construction, except that provided under section 6 of the 1928 act, had been performed along tributary streams. As previously noted, the St. Francis River and White River backwater features of the project were not authorized until 1936. The 1936 act also adopted the initial Yazoo Basin Project. The Augusta to Clarendon levee and the DeValls Bluff protection were not made a part of the project until 1946. The only levee construction on the north bank of the Arkansas River had been that performed under authority of section 6 of the 1928 act, and the portion below Plum Bayou was incorporated into the project in 1946.

The main-stem levee system has a total length of 2,193.7 miles. The figure includes levees, floodwalls, and various control structures. Of this length, 1,599.3 miles lie along the Mississippi River and 594.4 miles lie along the south banks of the Arkansas and Red Rivers and in the Atchafalaya Basin. There are 234.2 miles of levee along the Mississippi River that are slightly deficient in grade or section at scattered locations, including 50.5 miles of the New Madrid Floodway frontline levees that are to be enlarged

in accordance with the 1965 Flood Control Act, and 129.4 miles below New Orleans deficient in grade. All of the levees along the south bank of the Arkansas River and all but 8.2 miles of levees on the south bank of the Red River are complete. However, in the Atchafalaya Basin there are 134.5 miles of levees that are deficient in grade from minor to major amounts, and 133.0 miles that are presently completed to grade but that are deficient in section. In summary, 1,683.8 miles of the 2,193.7 miles in the main-stem levee system have been completed. About 1,121 miles of surfaced roads on levees are completed.

Elliott has described the evolution of levee construction procedures from primitive methods of digging and placement by manpower (see figure 45) to the use of tower machines, draglines, tractor-drawn dump wagons, dump trucks, and dredges for earth excavation, movement, and placement, and the use of bulldozers for dressing slopes (see figure 46). In 1932, the larger dragline machines in use handled from 3-1/2- to 10-cubic-yard buckets on booms ranging in length from 125 to 165 feet, with an average hourly capacity of 150 to 250 cubic yards, depending on size of bucket and length of boom. Smaller draglines were used for the loading of hauling equipment with booms about 45 feet long and 1- to 3-cubic-yard buckets, having an average hourly capacity of 100 to 175 cubic yards. The cableway machines were equipped with 6- to 12-cubic-yard buckets and had an average capacity of over 350 cubic yards per hour. Sixteen Government-owned levee machines were in use. During the year, four of the 21 owned the preceding year had been transferred from the Second New Orleans District to the Memphis District, and, together with one of the Memphis machines, had been converted into mechanical bank graders for use in bank protection work. Most of the levee construction was performed by contract. At that time, the trend of levee-building equipment owned by contractors was toward draglines, tower excavators, hydraulic pipeline dredges, and clamshell dredges.

Generally, improvements in construction methods and equipment during the period from 1932 to 1972 were not spectacular. The tower machine or cableway gradually faded out of the picture because the conditions which had made its use economical disappeared as levees were completed to approved grade and section. For efficient operation of these giants, it was necessary to have opposite borrow within a reasonable distance (preferably not in excess of 800 feet, but certainly no more than a quarter of a mile) and to have a large levee section so that the machine would not be required to move at frequent intervals. During the 38-year period, hauling units with capacities of 13 to 40 cubic yards have replaced the earlier 6- to 10-cubic-yard units, and rubber tires are replacing the crawlers formerly in general use. In addition to dump wagons that are loaded by small draglines in place of the elevating graders used in 1932, self-loading scrapers with capacities of 18 to 20 cubic yards are in general use for earthmoving. Some levee construction is still performed by large draglines, generally 150- to 180-foot booms with 5- to 8-cubic-yard buckets. On new work, such as the Yazoo backwater levee, it is not unusual to see large draglines working in tandem. For this type of operation, one machine casts material from the back of the borrow pit to the berm or to a point near the front of the pit, and the second machine moves the material into the levee section. Costs are not greatly in excess of costs of the work formerly done by tower machines.

Increased knowledge of soil properties and the development of efficient compacting equipment make it possible to construct levees having lower permeability, with fewer and smaller voids, and with lower shrinkage factors. But, actually, the construction methods used in the lower Mississippi Valley have changed little from those practiced in 1932. The high degree of compaction used for earth dams is not required for levee work on the lower river because the higher cost of such construction is considered unwarranted. The consensus of experienced levee builders is that compaction in addition to that obtained by movement

Figure 45. Manpower–and mulepower–required for construction of early levees in lower Mississippi River Valley

Figure 46. Modern levee construction equipment

of rubber-tired hauling equipment of large capacity is not needed. Long periods of time ordinarily elapse between completion of construction and occurrence of high river stages and, during such periods, further consolidation occurs. Evidence points to the fact that only a very few levees have failed because of inadequate compaction. Further improvement in the levee structure has been brought about by prohibiting the use of sand in the levee section, although it may be used in berm construction.

Channel Improvement and Stabilization

In his account of the improvement of the lower Mississippi River for flood control and navigation, Elliott observed that, although the term "bank protection" describes its fundamental purpose, the direct purposes may include prevention of cutoffs; prevention of undue widening of the navigation channel by bank erosion; improvement of river harbors; and, when economically justified, the protection of levees from bank caving. He described the experimentation out of which was developed the revetment types used in 1931. Details are also contained in Jackson's *Bank Protection on Mississippi and Missouri Rivers,* published in 1935. Elliott also pointed out that, prior to 1928, dredging was the main means of maintaining channels in the lower Mississippi but that the new project called for river regulation by means of contraction and bank protection works. However, it was not expected that the new program would eliminate all need for channel dredging, and it was doubted that the point would ever be reached when maintenance dredging would be entirely unnecessary on the lower river.

As of 1972, bank revetment, contraction works, and improvement dredging continue to be the means by which channel improvement and stabilization are sought. As previously described, the Flood Control Act of 1944 authorized execution of a channel improvement and stabilization program in the interest of flood control and navigation at an estimated cost of $200,000,000 over that then authorized.

The Flood Control Act of 1965 authorized additional bank protection improvements above Baton Rouge and extension of the work below Baton Rouge. The normal channel of the river above Baton Rouge is relatively shallow and subject to frequent and large variations in stage, resulting in powerful attacks on the riverbanks. A total of 607.8 miles of effective bank revetment was constructed on this part of the project between adoption of the basic plan in 1928 and 1972. This was accomplished in a progressive manner generally from upstream to downstream points. Intermediate control points, such as cities, important bridges, or natural resistance features of the terrain, were used as beginning points for works to be extended in a downstream direction. The length of revetted banks in bends generally was held to the minimum needed to hold banks where undesirable erosion had been occurring or threatening to occur.

Observations of completed work extending over many years show that a revetment must be extended upstream and downstream in successive increments as the river adjusts to its restrictive influence. On the basis of such observations, a long-range master plan for stabilizing the river between Cairo and Baton Rouge was prepared. The design principle was to lead the river into a more efficient alignment through a series of predetermined actions, and then to fix the river in its permanent alignment when the realignment had been achieved (see figure 47). The plan contemplates the use of contraction works to encourage deposition of sediment in auxiliary channels and confine low flows to a single channel, and also the use of dredges to assist the contraction works by developing primary channels and closing or causing deterioration of secondary channels. The plan includes additional revetments to augment existing revetments, some of which were originally constructed for protection of the levee system. The 1965 authorization covered the estimated cost of accomplishing the stabilization contemplated by the master

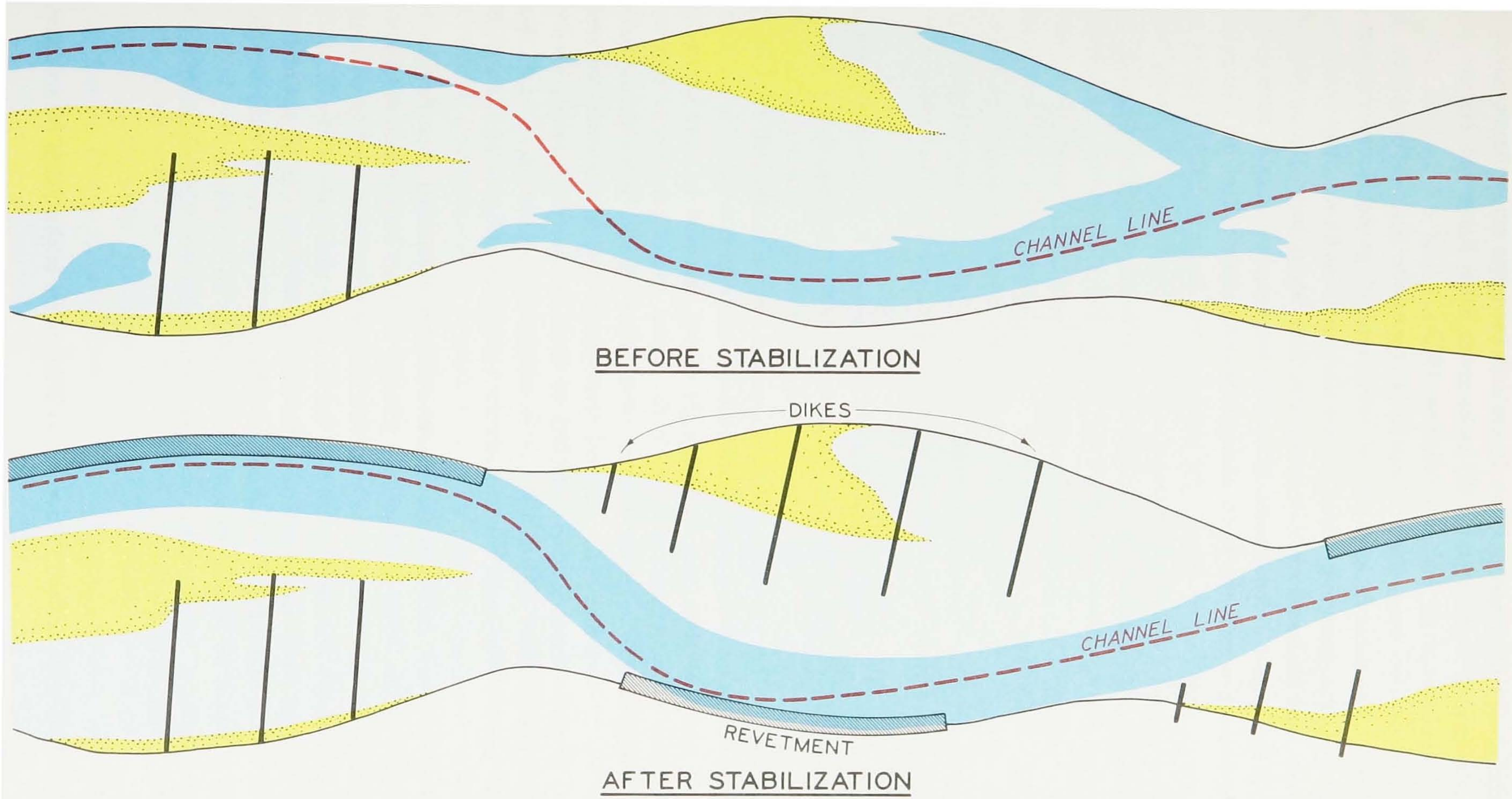


Figure 47. Example of Master Plan for Stabilization of Lower Mississippi River

plan, which included 635 miles above Baton Rouge and 145 miles below Baton Rouge, a total of 780 miles of revetment. Of these amounts, 601 miles above Baton Rouge and 74 miles below Baton Rouge had been completed at the end of Fiscal Year 1972.

Stabilization of the river below Baton Rouge involves problems quite different from those above that point. The river below Baton Rouge is generally very deep with general characteristics of an estuary during low flows and of a great river during normal flows and floodflows. Stage variations are much less, velocities lower, and the banks are more stable than those above Baton Rouge. Although the rate of bank caving is less than that above Baton Rouge, the long-range problem of controlling the river's meandering is nevertheless urgent. The width of usable land on either side of the river before reaching marsh or lake areas is quite limited. Because the highest ground lies immediately adjacent to the river, levees were placed as near the banks of the river as practicable to conserve the usable land. Usually, the best foundation material is likewise located adjacent to the riverbank. Although this permits maximum use of the best lands and optimum design, it also results in minimum foreshore between the levee and the river. Density of population and extensive developments by industry in the narrow bands of usable land behind the levee along each side of the river in this reach make stabilization of the river channel necessary. The cost of relocation of levees to prevent their destruction by caving banks would greatly exceed normal construction costs because of the many major relocations involved. Moreover—and most importantly—land taken by the river is lost, and this valuable asset is permanently reduced.

Since 1928, the revetment constructed in the 230-mile reach below Baton Rouge has been in locations where flood control structures were threatened with destruction and it was less costly to install revetment than to relocate the levee and related works and other improvements. However, such a procedure is not adequate and is not in keeping with the rapid economic development. The plan devised for protecting the levees through this reach envisions a progressive stabilization program extending over a 20-year period. This program will permit the river itself to develop the desired alignment in many sections and, at the same time, will allow for considerable variation in the annual rate of construction by treating major meanders on a priority basis to avoid the need for further levee setbacks. It is expected that one result of this program will be to permit those industrial developments that are dependent on availability of processing water in great volume, and on availability of water transportation, to locate with assurance that the sites and improvements thereon will not be endangered by a meandering river. The plan for river stabilization below Baton Rouge contemplates the eventual construction of at least 145 miles of articulated concrete revetment.

As previously mentioned, erosion of the foreshore between the riverbank and the levee is a serious problem below New Orleans, where the banks are generally at about the elevation of normal low water and are exposed to year-round damage. The most effective and economical remedial works have proved to be stone or broken concrete dikes, parallel to the bank line and situated as near as security will permit to the top of the bank. The authorization provided by the Flood Control Act of 1965 included funds for approximately 100 miles of foreshore protection. It is planned to build this protection in large increments as rapidly as possible to stop further damage to the batture.

Review and updating of the master plan, which was the basis for the 1965 authorization, are proposed to be undertaken in Fiscal Year 1975.

Bank revetment

Reference has been made earlier to Elliott's description of the origination of the articulated concrete

mat and eventual adoption of a standard mat design for use throughout the lower valley. His account also describes construction of the mat units on a floating casting plant, as well as the sinking operation then employed. Although few basic changes have since been made in the design of the mattress or in the technique of bank grading, many improvements have been made in the manufacturing and placing processes that have contributed to greater efficiency and economy of operation. The integrity (and consequently the useful life) of the mattress depends on the life of the reinforcing fabric, for which reason copper-coated steel or stainless steel are now used for metal parts.

Casting fields at several convenient locations on the riverbank have superseded the floating casting plant. An example is depicted by figure 48. These fields have storage capacities of 40,000 to

Figure 48. Mattress storage field

380,000 squares, making it possible to store quantities of mat adequate for seasonal demands. Considerable mechanization of the casting process has been accomplished, including delivery of bulk cement to the casting field by tank trailer trucks or barge for storage in a silo, screeding and vibrating of the filled form, placing of kraft paper between succeeding layers of mat (previously a hand operation) and water curing and spraying with membrane curing compound. Many hand operations are still required, such as placing of fabric in preparation for the casting of another tier of mat. Experimentation with various concrete mixtures has resulted in the present-day use of 3-1/2 bags of cement per cubic yard of concrete in place of the 4 to 5 bags used in earlier mixtures. This saving in cement, combined with the increased production made possible by improved and mechanized operations, has enabled casting costs to be held to an increase of about 15 percent since 1948. The production rate for the floating casting plant of 1931 was approximately 600 squares per 10-hour shift, so substantial improvement has also been attained in production as shown by the increase in average hourly production of field casting from 100 squares in 1948 to a maximum of 200 in 1970. Figures 49 through 54 illustrate stages of field casting of mattress as currently performed under contract.

A distinct improvement in manufacture of concrete mattress has been made by the development and construction at Greenville, Mississippi, of an indoor automatic casting plant, fully mechanized, developed by Colonel George F. Dixon, District Engineer, Vicksburg Engineer District. This plant can be operated under all weather conditions. Figure 55 is a cutaway sketch of the plant that batches and

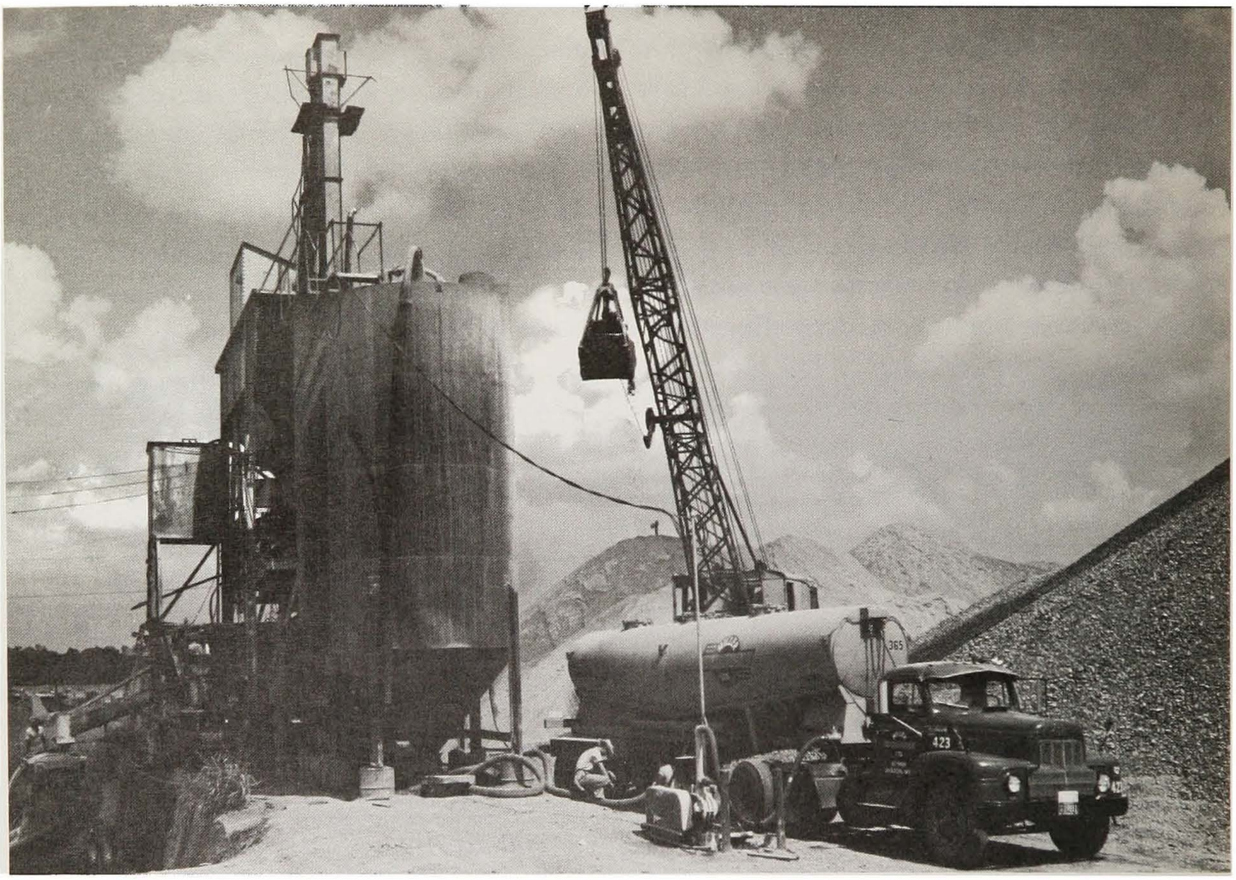


Figure 49. Field casting of mat–unloading cement and delivery of aggregates

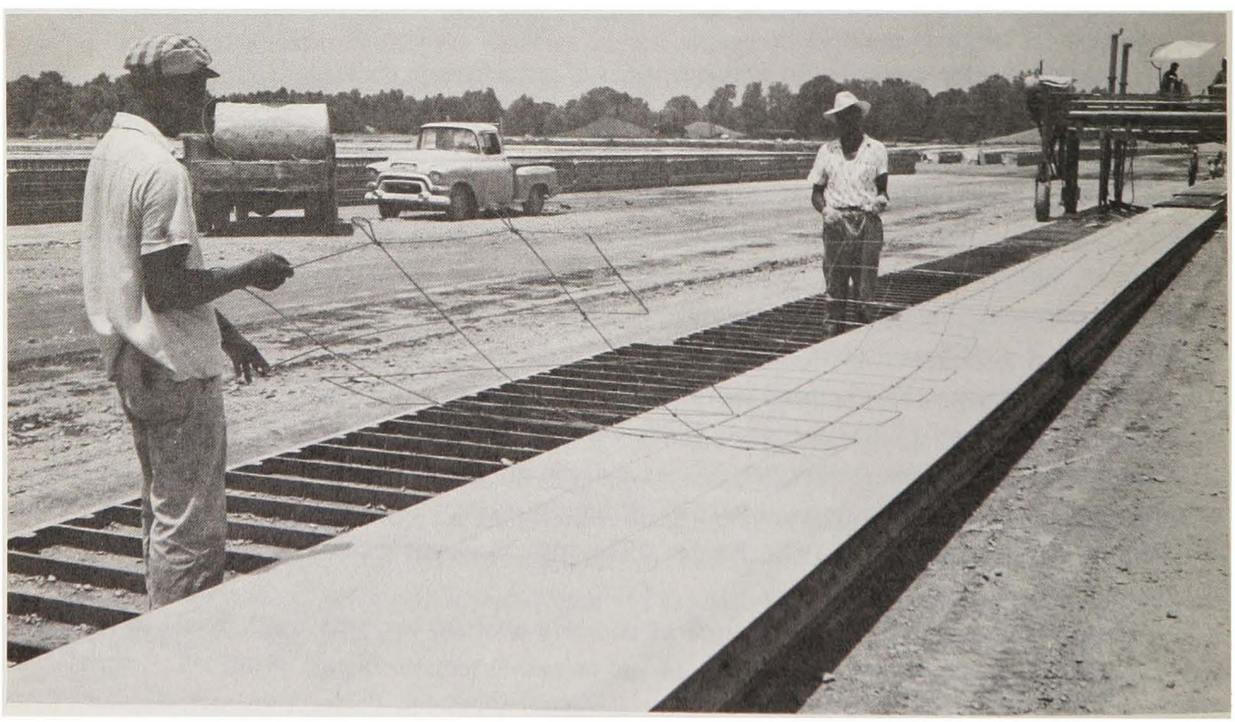


Figure 50. Field casting of mat–placing reinforcing fabric on bottom of form

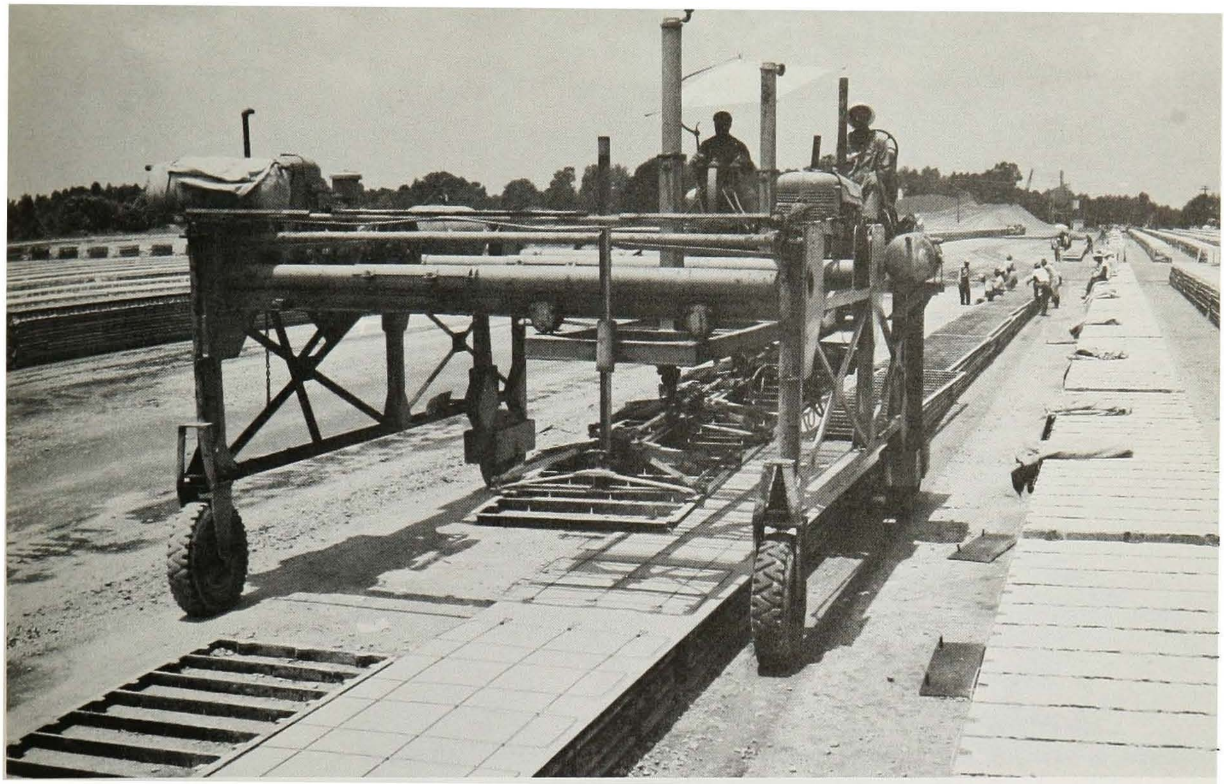


Figure 51. Field casting of mat–placing form for blocks

Figure 52. Field casting of mat–placing concrete in forms

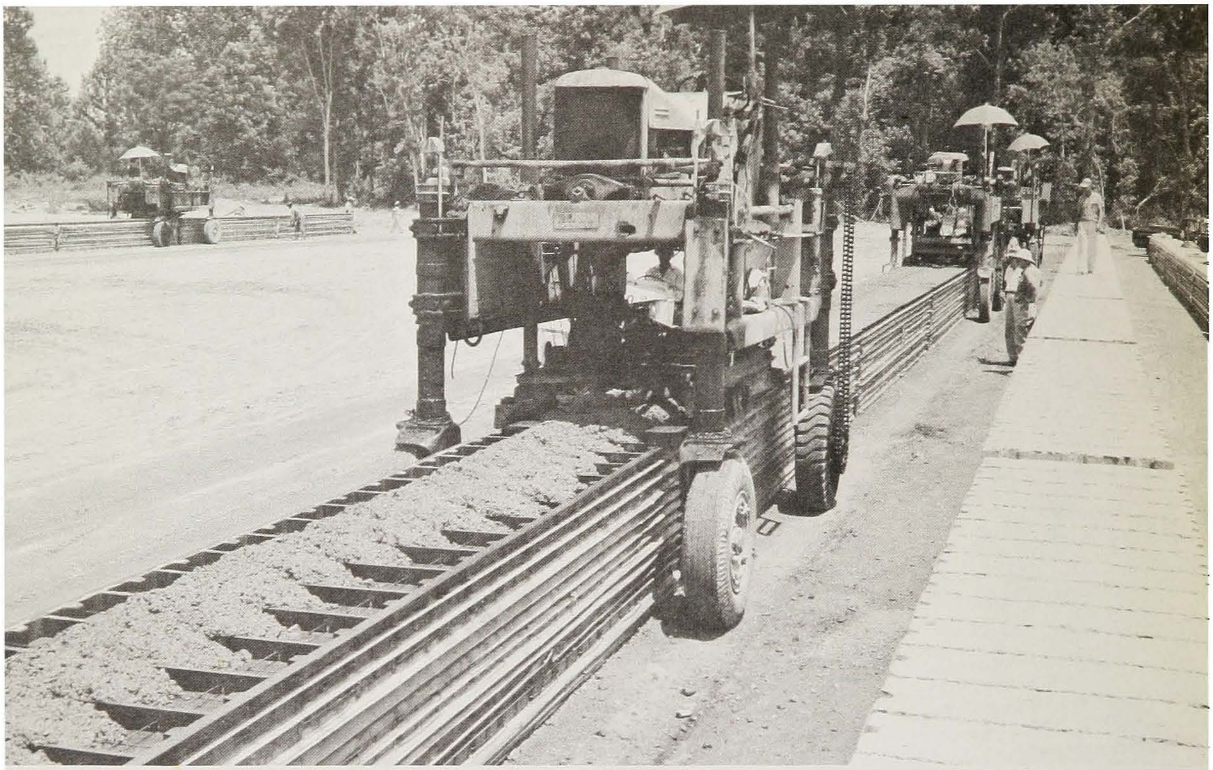


Figure 53. Field casting of mat–screeding machine spreading concrete

Figure 54. Field casting of mat–vibrating and final finishing of concrete

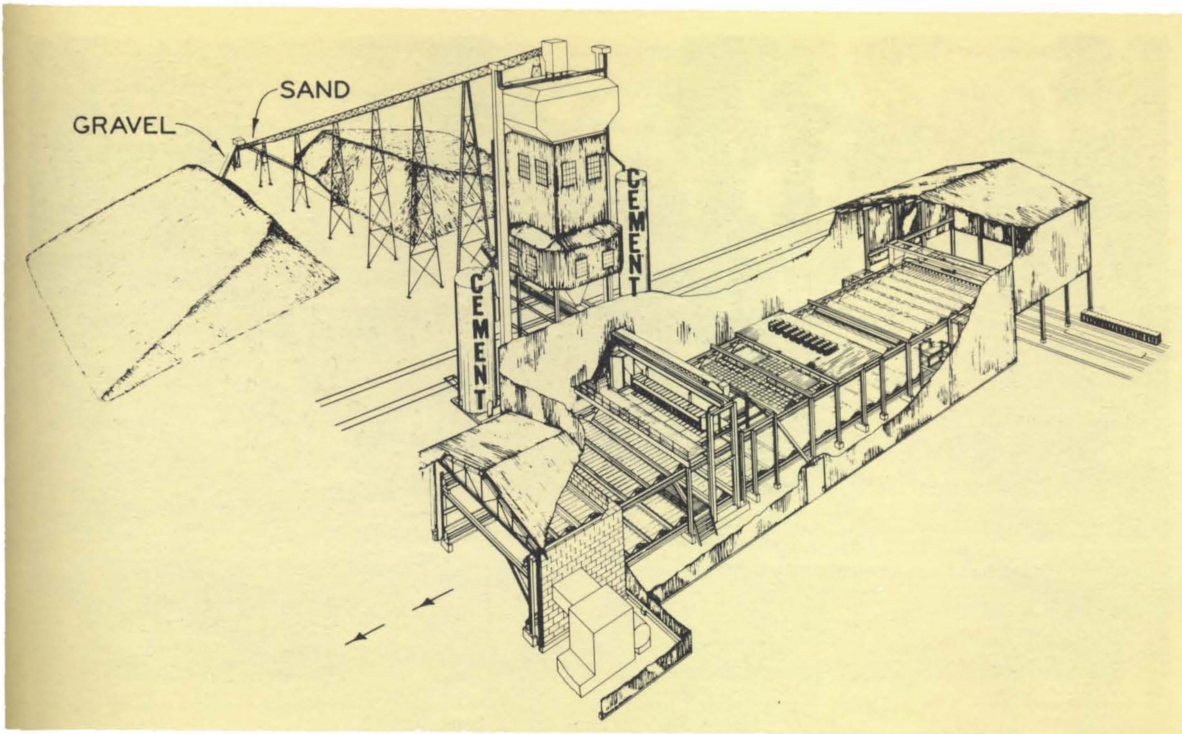


Figure 55. Layout of automatic casting plant

mixes the concrete, places it in the mold box, steam cures, removes the mat units from the conveyor belt, and stacks them in the open field for further curing. The complete cycle, with the conveyor belt traveling at 6 feet per minute, requires 2 hours and 41 minutes. The plant was completed in June 1955 and was initially operated by Government hired labor. Later, it was made available as Government-furnished equipment for production of concrete mattress. Although maximum capacity is 80 squares per hour, the contractor is limited to a maximum production rate of 70 squares per hour in order to minimize maintenance costs. The principal advantage of the automatic plant over field casting is that production can continue at Greenville without a shutdown due to weather, even if temperatures should drop below freezing.

Subaqueous-grading and mat-sinking operations are not commenced until the river stage has fallen to 15 feet above mean low water. Normally, if a sustained rise above 15 feet were in prospect, these operations would be suspended. This restriction limits revetment placement to the low water season, usually between mid-July and mid-December, and requires its cessation about the first of January, subject to the availability of funds to carry out the season's program. In emergencies, mattress has been placed when the stage was as high as 25 feet above the average low water plane, river currents and drift conditions permitting. The upper limit of concrete subaqueous revetment is normally 6 feet above average low water.

The initial operation in preparation for placement of subaqueous revetment and upper bank paving is the clearing and grading of the bank (see figures 56 and 57). Hydraulic bank graders, by which this work was done as early as 1879, had a number of inherent disadvantages which led to their eventual abandonment in favor of mechanical grading. The principal item of equipment now used is a floating dragline, usually with a bottomless 15-cubic-yard bucket. After clearing of trees and other vegetation has been completed, the bank is graded uniformly to a slope predetermined by soil analyses, usually

Figure 56. Typical caving bank

Figure 57. Bank grading in preparation for placement of revetment

1 on 3 to 1 on 4. Several bulldozers are used in conjunction with each bank grader, dressing the bank and pushing materials toward the dragline bucket, thereby speeding the grading operation. The grading starts at the top of bank and is carried to a depth of about 30 feet. The spoil material is pulled as far into the river as practicable for entrainment by the current. Dredging may be required in shallow bends if the stream does not satisfactorily dispose of the surplus material.

Placement of articulated concrete mattress on the underwater slope has been facilitated in recent years by changes in design of the mattress sinking plant and development of a "mat puller" to assist in positioning the inshore edge of the mattress in certain situations. Changes in the mattress sinking plant design included widening the deck to accommodate two launches of mattress at a time, which permits the assembly of one launch to be in progress while the succeeding launch is being placed on the deck by electrically powered gantry cranes which have replaced the steam-operated whirley cranes previously used (see figure 58). The changes in plant design have greatly increased the speed and efficiency

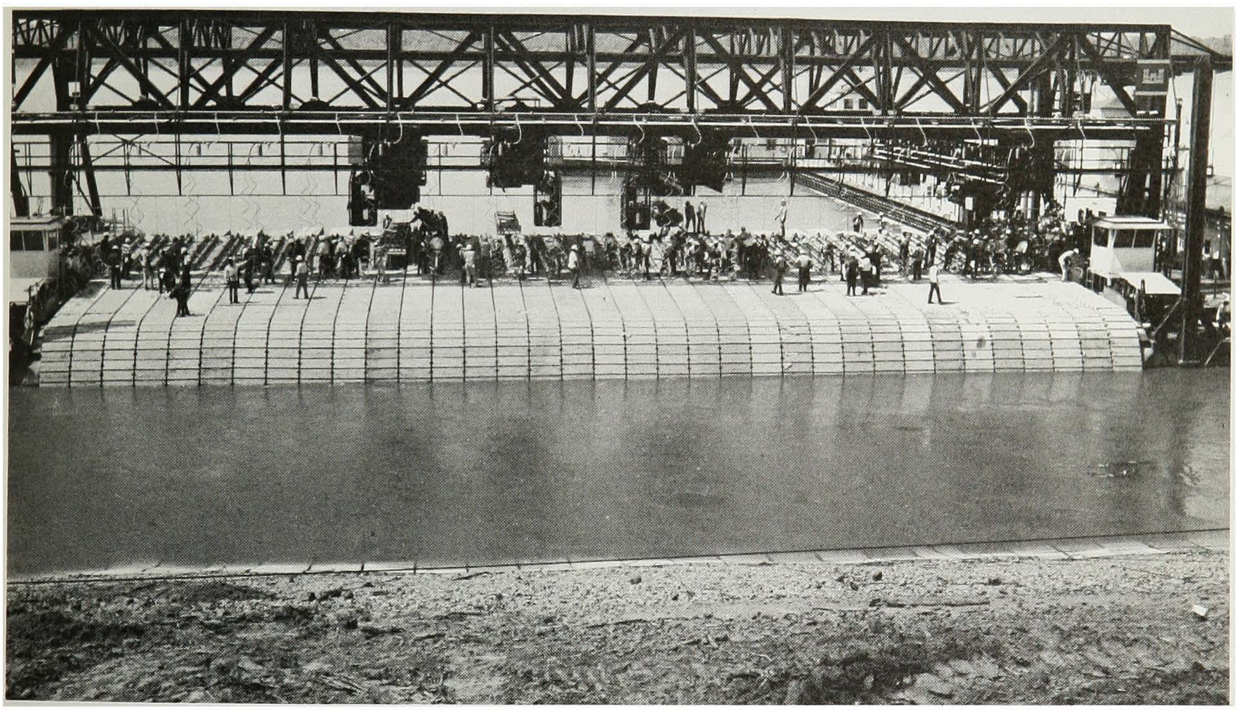


Figure 58. Launching articulated concrete revetment from mattress sinking plant

of the mattress-sinking operation. As of 1972 there are two articulated concrete mattress-sinking plants in operation on the lower river, each designed to place a subaqueous mattress 140 feet wide. One plant has three gantries and the other has four. The previous average daily placement of about 6,800 squares per 20-hour day for the two plants has been increased to over 10,000 squares per day. The mat puller (see figure 59) was planned for use where the riverbank is irregular in relation to the alignment of the river channel, with the result that one edge of the articulated concrete mattress might be placed above the waterline on the bank, but the opposite edge might fail to reach the water's edge by 20 feet or more. Before this device was developed, repositioning of the entire mat plant was necessary to place small sections of the mattress. This special piece of equipment remedied the difficulty by enabling the subaqueous mat to be pulled up the bank so that the lower edge of the mat will be at the waterline.

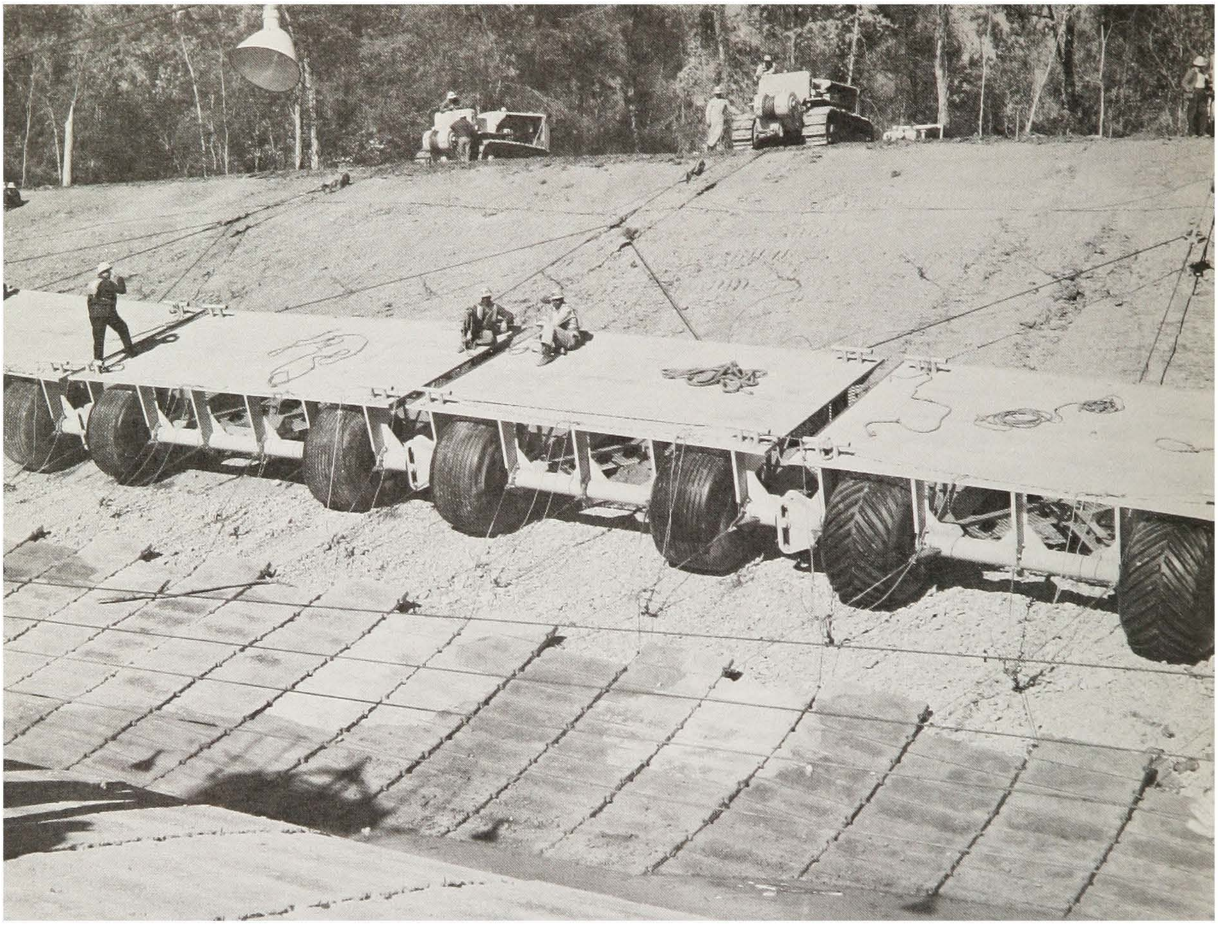


Figure 59. Mat puller rig

The puller consists of a steel frame mounted on 28 large pneumatic tires that float the platform at the landside of the sinking plant prior to the start of the pulling operation. Tractive power is supplied by winch tractors positioned on top of the graded bank.

In order to prevent damage to the exposed bank in case of a rising river stage, the upper bank is paved as soon as possible after the subaqueous mattress has been placed. Prior to 1931, monolithic concrete pavement was considered to be the cheapest and most effective upper-bank pavement that had been produced up to that time. It was favored because of the belief that it withstood the action of drift better than riprap or concrete blocks. It was designed to be 4 inches thick and was placed on a carefully prepared 1-on-3 slope. At the upper edge of the pavement, an inverted wedge-shaped curb was cast integrally with the slab. The curb penetrated to a depth of 3 feet and served as a cutoff against undermining by surface drainage. Provisions were made for expansion joints, and for French drains and weep holes for relief of hydrostatic pressure. Care was taken to provide an impervious junction between the upper-bank paving and the subaqueous articulated concrete mattress. Riprap upper-bank paving also has been used extensively. It was 10 inches thick and was laid by hand. The junction between a concrete subaqueous mat and riprap paving required special treatment. The riprap was required to overlap the articulated concrete mattress by three blocks and to be 20 inches thick at the upper edge of the mat,

Figure 60. Placing uncompacted asphalt upper bank paving

decreasing to a thickness of 10 inches at a distance of 6 feet up the bank. Above this zone, the riprap paving extended to the top of the bank.

Uncompacted asphalt upper-bank paving, developed in 1945 to meet requirements for the expanded project (figure 60) was initially thought to be superior to monolithic concrete or compacted asphalt pavement because of its free-draining characteristic. It was not used above Memphis; below Memphis, it supplanted all other types, including compacted sheet asphalt pavement which had been used extensively in the New Orleans District. Above Memphis, the availability of rock favored the use of riprap pavement (figure 61).

Experience has shown that rock is the better material. It adjusts to slope irregularities and reforms when minor bank subsidence and sloughing occur, continuing to afford the protection for which it is designed. It has a long life and requires little maintenance. However, the remoteness of rock quarries below Memphis, together with limitations on the supply of barges and of qualified suppliers, caused riprap to be high in cost on the lower river. An additional factor contributing to this high cost was the seasonal concentration of requirements within a comparatively short period. In recent years, new quarries have been opened and more barges have become available. As a result, much more favorable bids have been received for riprap, the average price being about $4.00 per ton in place, equivalent to $18.00 per square. The costs of uncompacted asphalt upper bank paving in Fiscal Year 1964 averaged about $20.73 per square.

Asphalt upper-bank pavement was abandoned in 1965 and riprap is now specified for all main-stem revetment construction on the lower river. The stone, in pieces weighing from 6 to 125 pounds each, is placed as previously described from the inshore edge of the subaqueous mat to the top of the graded bank or to a predetermined elevation, as specified. A gravel, crushed stone or shell blanket 4 inches thick is used under the riprap up to the midbank point or, in some cases, to the upper limits of the paving, based on the ground-water or seepage plane, as a filter to prevent soil from being leached through the revetment interstices. Stone is placed by skip or clamshell and is rearranged by hand, as necessary, to obtain a compact paving with uniform thickness. Figure 62 illustrates the completed bank protection.

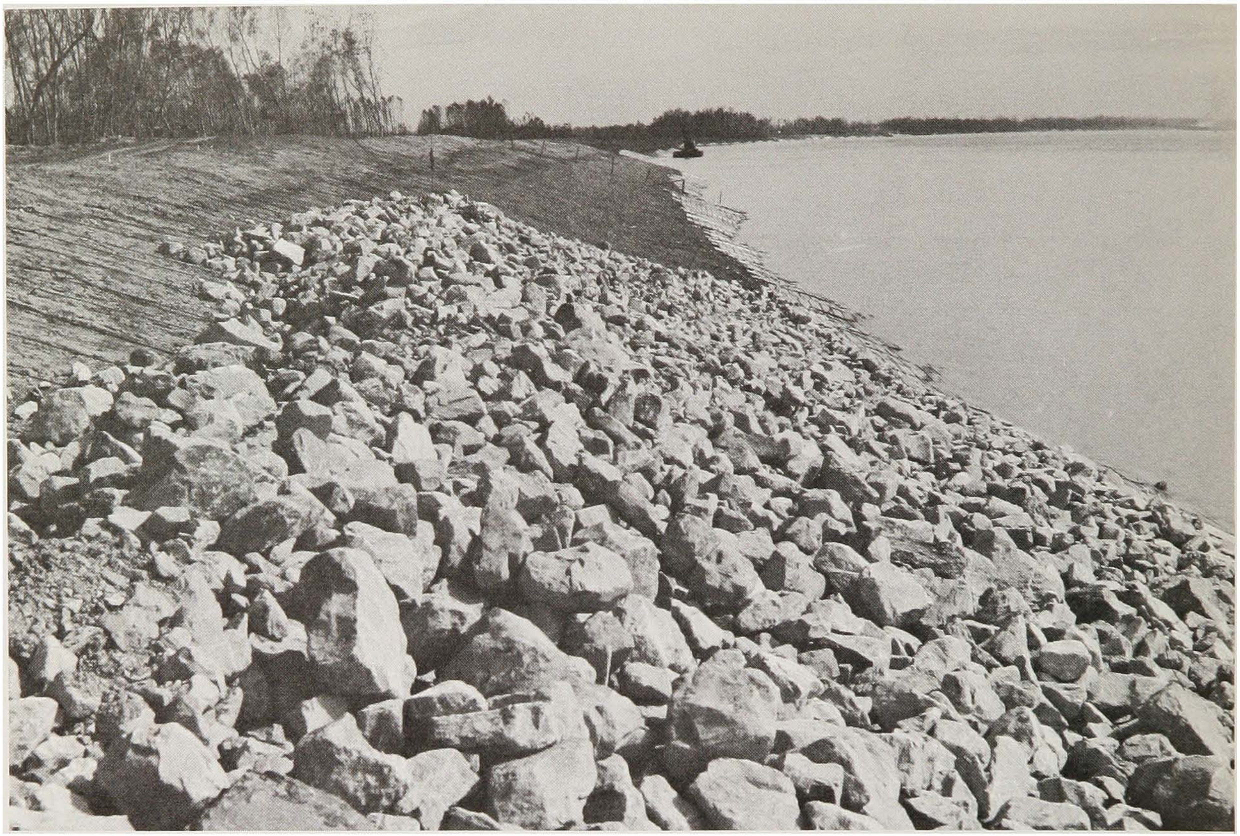


Figure 61. Riprap upper bank paving

Figure 62. Completed revetment showing upper portion of articulated concrete mattress and riprapped upper bank

Continued improvements have been made in the manufacturing and sinking of articulated concrete mattress, and as a result, the in-place cost of concrete mattresses has been held down despite steady rises in labor and material costs. From 1932 to 1972, the rise in total revetment costs has been well below the increase in the Engineering News-Record construction cost index for the same period.

Contraction works

Contraction projects were included in the earlier construction on the lower river to reduce excessive channel widths that were responsible for poor navigation conditions. The initial works under sponsorship of the Mississippi River Commission included not only channel contraction structures, but also chute and secondary channel closures. They were not successful. Dredging was then utilized as a means of maintaining the navigation channel, and this constituted the standard method at the time of adoption of the project by the 1928 act. The new project called for river regulation by means of contraction works and bank protection. It was anticipated that limited amounts of dredging would still be required during periods of extreme low water and in localities where the need for improvement was intermittent and the expense of permanent works was not justified.

Channel contraction works include all structures designed to restrict low water flows to a channel narrower than its natural one. They are usually constructed in the convex part of bends and where the channel crosses to the opposite shore. They are also employed to assist in closing secondary channels and chutes. The individual units of a system of contraction works are built at an angle to the current direction and are spaced intermittently along the bank at distances dictated by site conditions. The structures may be permeable or impermeable, depending upon their function, the site conditions, and materials used in construction. A form of permeable dike as constructed on the lower river is depicted in figure 63. It consists of from one to four rows of pile clumps, depending upon the depth of water and lengths of unsupported piling, with lumber mattress or stone foundation. The pile-dike system consists of riprap paving on the graded upper bank, a single pile root dike above the water surface, a shore mattress of variable width extending riverward about 100 feet from the water's edge, a foundation mattress of variable length extending riverward from the shore mattress (see figure 64), and an L-head mattress for the outer 100 feet of the dike. The piles are driven through the mattress in clumps.

The use of such structures on the lower Mississippi River has been limited because of the magnitude of the discharge and the stream velocities. Construction necessarily took place during the low water season, and some structures were partially or completely destroyed during periods of high discharge and velocities. Closing of a secondary channel by this means proved to be extremely difficult or impossible due to high velocities or deep water. Other hazards to these structures included large quantities of drift, deterioration of piles, corrosion of hardware by river water, and flanking due to channel alignment. From 1928 to 1935, 201,200 lineal feet of permeable pile dikes and crib dikes, all located in the Memphis District, were constructed. This completed the contraction work authorized by the 1928 act. Although these works contributed substantially to provision of a 9-foot navigation channel, they deteriorated badly upon exposure to severe attack by scour, ice, and drift accumulation, and due to lack of maintenance. At that time, channel stabilization did not have a high priority status, hence unstable channels and bank conditions resulted. Many of the dikes in the system were damaged, destroyed, and flanked by the meandering channel. Some of the dike remnants menaced the relocated navigation channel and were finally removed by dredging operations. Remnants of a few of the early works are still partially effective and have been utilized in recently constructed dike systems. Other systems have become inoperative due to river migration.

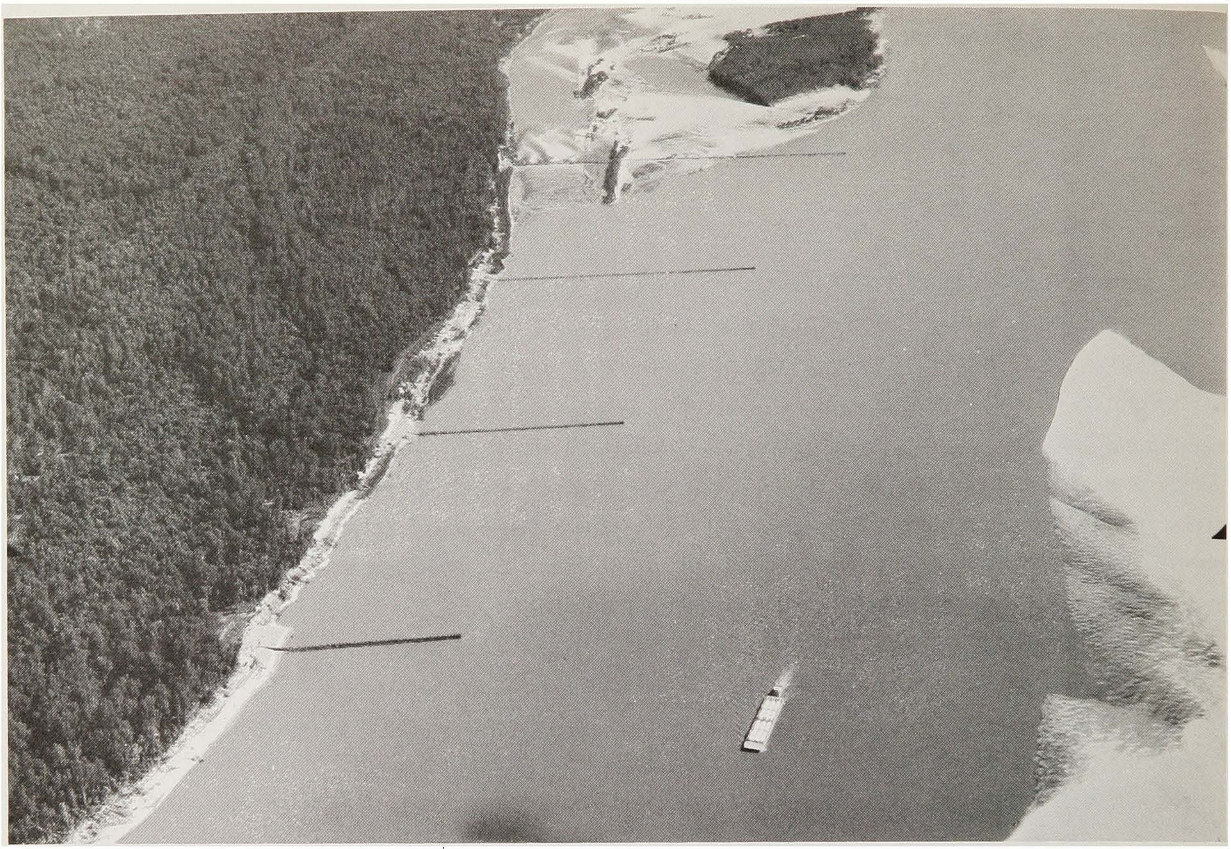


Figure 63. System of pile dikes designed to close secondary channel

Figure 64. Foundation mattress for pile dike construction

The channel improvement and stabilization program authorized by the Flood Control Act of 1944 included revetment, dikes, and dredging. Construction of permeable dikes was resumed under this authorization in 1956, by which date enough revetment work had been completed under the 1944 authorization to control the major reaches of active bank caving. These dikes were constructed to a top elevation of 13 to 15 feet above the low water plane. The types used, their limitations, and susceptibility to destructive forces were essentially unchanged. In an effort to provide resistance to severe attack, additional pilings were used and the piles in the outer 90 feet were treated. Wire rope and hardware of corrosion-resistant metal were used to aid in prolonging structural life. Other changes were made to improve the dike structure. Despite these betterments, the permeable pile dike continued to show objectionable effects from scouring action, deterioration, and damage from tows operating over and through the dike system during high stages. Early accretion necessary to preserve the dike system and produce the desired channel contraction did not take place. It was concluded that a less permeable dike was necessary, and, in 1964, the Memphis District began building stone dikes, which had been successful elsewhere. Some dikes were entirely of stone; others were stone-filled permeable pile dikes; and some existing pile dikes were filled with stone. The design of an all-stone dike (see figure 65) included a riprap bank head, a foundation or base section, and a crown width varying from peaked to 20 feet, depending upon the height of the dike, placed on the foundation section to an approximate elevation of 15 feet above low water. For reasons of economy, quarry-run stone has replaced graded stone for use in dike construction. The specification calls for 50 percent of the material, by weight, to consist of pieces weighing not less than 500 pounds, or more than 3,000 pounds. Lower bid prices were obtained for the quarrystone, which has been found to be as effective for the purpose as graded stone. In addition

Figure 65. Constructing stone dike for chute closure using quarry stone

to permanence of material, stone dikes start to accumulate fill as soon as they are in place due to the almost complete cutoff of flow. They are not easily damaged by tows or by ice, and consequently are lower in maintenance costs.

On the main stem of the Mississippi River from 1956 to 1972, about 92 miles of dike construction were completed in the Memphis District. There were 56 dike systems in all, including permeable dikes, stone dikes, and combinations of the two. In the Vicksburg District, extensive use of dikes for channel contraction did not begin until 1961. By 1972, there were 27 dike systems in operation with a total length of 43 miles. The systems include stone, combinations of stone and piling, and piling dikes. Dike construction in the New Orleans District has been limited to Southwest Pass and to isolated localities on the Red River, the latter being constructed for bank protection.

In 1964 and 1965, there was some experimentation in the use of discarded automobile bodies as material for dike reinforcement or construction. In an experiment made at Below Race Track in 1964, 400 old car bodies were placed along the upstream side of three dikes in an existing pile-dike system to act as screens to induce more rapid filling in the dike fields. A second experiment at Reid-Bedford in 1965 used 607 old car bodies, exclusively, to construct a dike across a secondary channel. The bodies were stacked three high with three car widths on the bottom tier, two on the next tier, and one car on the top tier (figure 66). They were assembled on the deck of a specially constructed barge, from which they were launched in a continuous string after being lashed together with cables. Upstream anchors consisted of car bodies which had been filled with concrete. Hydrographic surveys made in October 1969 showed that those car bodies that were added to the existing pile dikes had not materially aided in the creation of a permanent fill in the dike system. Moreover, inspection during low water revealed

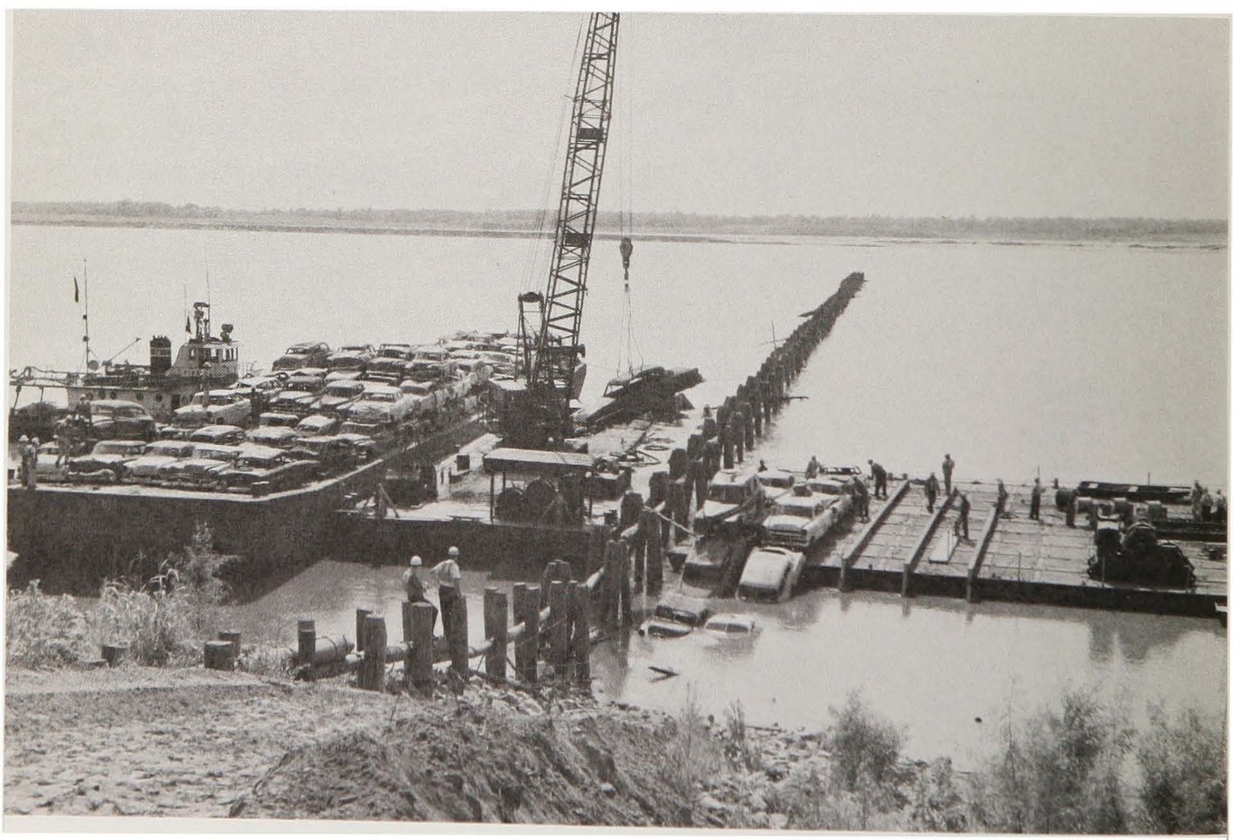


Figure 66. Car body dike placement along upstream side of existing dike

that the car bodies were rapidly deteriorating due to rust. Many of the cables used to tie the bodies together and by which they were suspended from the piling had broken or pulled out of the deteriorated car bodies, which resulted in from 6 to 8 feet of lowering from the as-constructed elevation. In order to preserve the integrity of the dike system, it was necessary to reinforce all of the dikes with riprap. At the site of the dike constructed wholly of car bodies, it was estimated that the maximum benefits to be expected from such a single, unsupported structure is a 5 to 10 percent reduction in discharge in the chute from that at comparable stages before the dike was constructed. It was concluded that old car bodies are unsuitable for such dike construction, particularly where permanent structures are required.

Another investigation conducted in 1964 concerned the merits of nylon and plastic materials for dike construction. Sand-filled nylon and plastic bags were substituted for stone in a short section of a stone dike being constructed on the Mississippi River at Forked Deer, Tennessee (see figure 67). The test section was so located that it was subjected to severe current and wave attack both during and after placement. Following a high water period, during which the dike was subjected to fluctuating river stages above and below the top elevation of the dike, inspection revealed that many bags of both types on the surface of the structure had been ruptured and the fill material lost. The damage was attributed to drift to which the structure was subjected during the lower river stages. It was concluded from this investigation that plastic bags are not suitable for use in dike construction because of the weakness of the material, which made it necessary to use small bags. On the other hand, it was thought that sandfilled nylon bags would be superior to stone in making closures or for initial placement in swift currents, although an armor of stone or other durable material would be required in permanent structures.

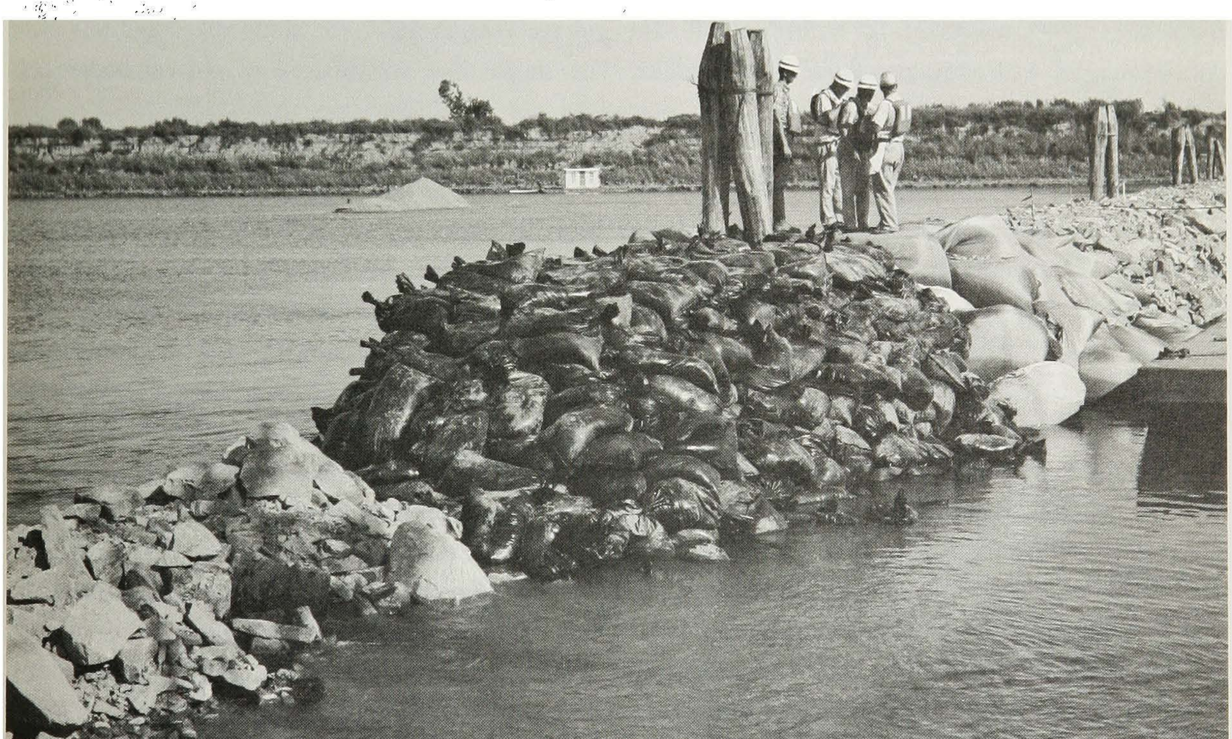


Figure 67. Experimental section of sand-filled nylon bags for dike construction

A model investigation is also underway at the Waterways Experiment Station seeking general information for use in design of dikes. The specific information desired includes the relative effects of dike crest elevation and crest profile, the effects of degree of permeability of dikes, the effects of dike spacing, the effects of angle and position of dikes with respect to currents and desired channel alignment, and the effects of changes in sediment load on dike performance. The investigation has not progressed sufficiently to furnish design data, hence only general conclusions are evident as to factors affecting the performance of dikes which should be considered in design. It is clearly indicated that dikes can be designed to produce better results at lower cost. It is also recognized that data from the field are needed for correlation with laboratory results before the basic principles involved in dike design can be firmly established.

At present, contraction works are the least understood of the stabilization works. The behavior of the recently introduced stone dikes has not yet been determined. Although construction of dikes will reduce the between-bank channel cross section, it is thought that the resulting riverbed degradation and the improved channel efficiency will partially, or perhaps wholly, offset the reduction in channel area. The dike study at the Waterways Experiment Station is expected to furnish data bearing on this important question. In addition, prototype observation and data collection will seek to determine actual effects of the construction of dikes and consequent changes in channel area.

Because dike construction costs increase as the depth of water in which the structures are located is increased, it is difficult to compare costs for the several types in use. Increase in cost with increase in depth is due both to the difficulty of operation at greater depths and to increased material requirements. Accessibility of the site is also an important factor. Average costs per lineal foot of permeable pile dikes have ranged from \$70 to \$95. Similar costs for stone dikes have been \$25 for a 5-foot fill, \$80 for a 15-foot fill, and \$275 for a 30-foot fill. The average cost in 1972 for stone dikes and pile dikes with stone fill was \$150 per lineal foot of dike. The single dike constructed of old car bodies cost about \$32 per lineal foot.

Dredging

In the broadest sense of the term, dredging includes subaqueous excavation by land plant as well as by floating plant, but on the lower Mississippi River, improvement and maintenance dredging are accomplished only by floating plant. It has been previously mentioned that, between 1896 and 1928, dredging was the principal measure used to maintain a navigation channel, and the only regulating works constructed on the lower river were planned to close objectionable chutes and secondary channels. After adoption of the 1928 act, the Commission embarked upon a program of river regulation by the systematic construction of contraction works, which, it was expected, eventually would greatly reduce, although not eliminate, such dredging. Shortening of the low water navigation channel between Memphis and Baton Rouge (described in chapter III under "Cutoff Investigations") was accomplished between 1932 and 1942 by construction of cutoffs and development of shorter chute channels. It was a monumental dredging task, requiring the speedy removal, and in some cases disposal, of large quantities of material, some of it located well above the water surface even during high water periods. Among other things, this made necessary the development of special plant capable of removing materials by dredging at depths greater than had been the practice previously.

In addition to the cutoff construction and supplementing it, an extensive program of channel improvement dredging, initiated in 1933 and continued through 1944, included cutting back projections in bank lines, making deep cuts in the desired channel locations, depositing dredge spoil as sandfills

or dikes to guide flow into the excavated channels, and closing chutes and back channels with dredged material. The purpose of this work was to obtain a single, efficient channel of good alignment in reaches where the channel had divided flow, indefinite location, or inefficient hydraulic characteristics. Each such operation was a major undertaking involving excavation and deposition of several million cubic yards of sand. Some were successful and some were not. None could be considered permanent because shifting of the river's alignment through the caving banks upstream of a job of improvement dredging eventually obliterated it.

Channel improvement dredging was continued through 1956 to promote development of a more desirable navigation channel; to assist the river in obtaining a suitable alignment; to remove remnants of old dikes; and to increase the flood-carrying capacity of the main channel following chute closure. Since adoption, in 1956, of the master plan for channel stabilization, improvement dredging has been performed to realign and improve the channel for stabilization and navigation.

Construction of the cross-country Interstate Highway 40 necessitated provision of a new bridge across the Mississippi River at Memphis. A location for such a bridge had been under discussion as early as 1943. Twenty years later, progress on the interstate highway system made it necessary to reach a decision. The site selected by the U. S. Bureau of Public Roads, in cooperation with the States of Tennessee and Arkansas, extended across the lower end of Mud Island to the Arkansas side at Hopefield Point, about mile 736.6 above the Head of Passes. Under the terms of the Interstate Highway Act, construction of the bridge was to be completed by 1972. One highway and two railroad bridges are located about 2 miles downstream from the site of the new bridge. Before additional piers which might prove to be hazardous to navigation could be placed in the channel, it was imperative that the reach be stabilized.

A channel stabilization project had been begun in 1956 on the 15-mile reach of the Mississippi River extending from Brandywine to Memphis, which included the new bridge site. The channel had long been unsatisfactory and unreliable for navigation, inefficient for floodflows, and expensive to maintain. By 1963, 10 miles of this stretch had been brought into the desired general alignment. The plan for stabilization of the river in the lower reach required a major shift of the river channel. It involved dredging to develop new channels and to maintain or enlarge existing ones; placement of articulated concrete mattress and riprap upper bank pavement to prevent undesirable bank recession and to preserve desirable alignment; and construction of dikes to encourage bar building in closing off secondary channels and concentrating flow in the desired channel.

Relocating 5 miles of river channel on an imposed schedule to meet a deadline was an accelerated procedure without precedent. The channel alignment in 1956 and stabilization plan are depicted by figure 68. The ultimate alignment and stabilization plan are depicted in figure 69. Dredging of the new river channel required the mechanical removal of a large portion of Mud Island, involving about 33 million cubic yards of excavation. Placement of such a quantity of material in the river would have had an adverse effect on the navigation channel. Hence a pilot navigation channel adjacent to the stabilization line was dredged first and most of the material was placed in prepared spoil areas on land between retaining dikes (see figure 70). One spoil area was located north of the Wolf River diversion channel, and the other was on Mud Island. The fills raised these areas about 20 feet, bringing them to an elevation above any anticipated flood. Upon completion of the pilot channel, revetment to stabilize the new east-bank alignment was placed, and navigation was routed via the new channel. The remaining portion of Mud Island west of the pilot channel was then removed by dredging and placed westwardly in the area where the Robinson Crusoe and Loosahatchie Bar dikes were then constructed to stabilize the low

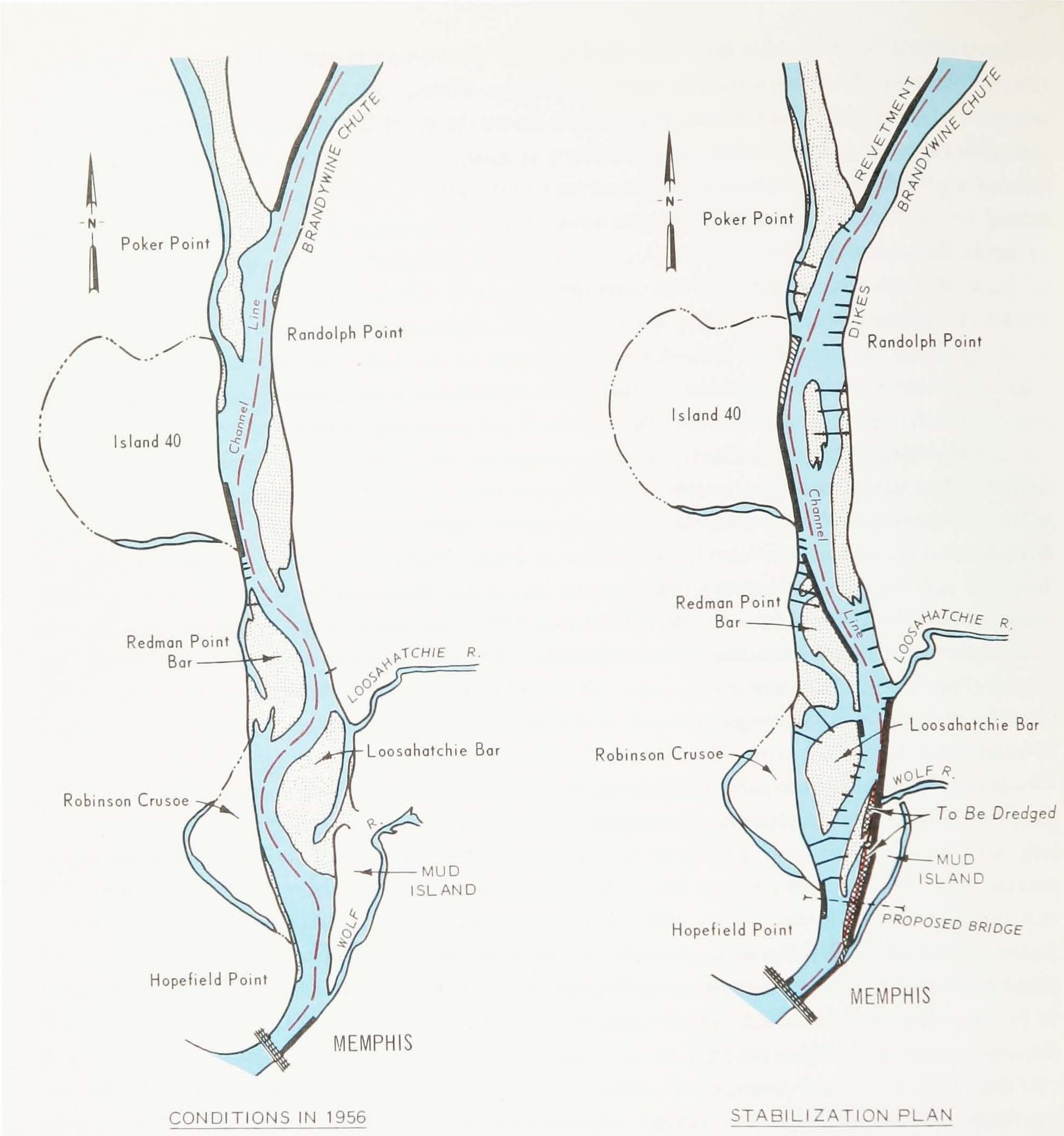


Figure 68. Brandywine to Memphis–channel alignment in 1956 and stabilization plan

water channel in the vicinity of the bridge. This plan had been completed by 1972 except for construction of stone dikes on the right bank in the vicinity of the new interstate highway bridge crossing. The bank in this area will not be available for the dikes until plant and equipment used on the bridge have been removed.

Maintenance dredging is primarily concerned with providing only the necessary depths and widths required for navigation in existing channels. Width and shape (that is, alignment and direction of currents) are frequently of more concern than obtaining depths. The shallowest places within the navigation channel are normally in the reach where the main channel crosses from one bank to the other. It is well established that on rising stages, sand is deposited in these crossings and that on low, falling stages, the sand is

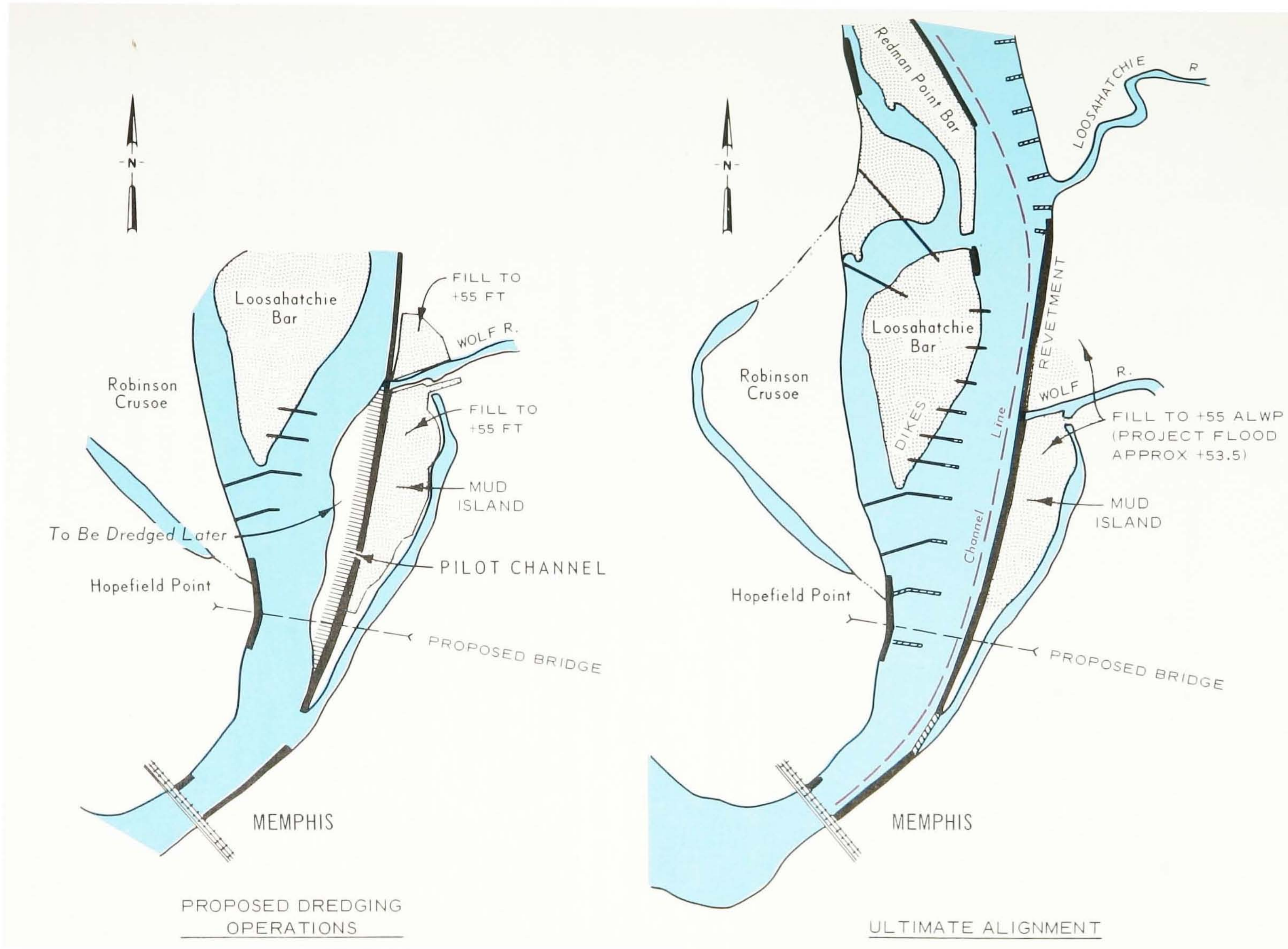


Figure 69. Brandywine to Memphis - ultimate channel alignment

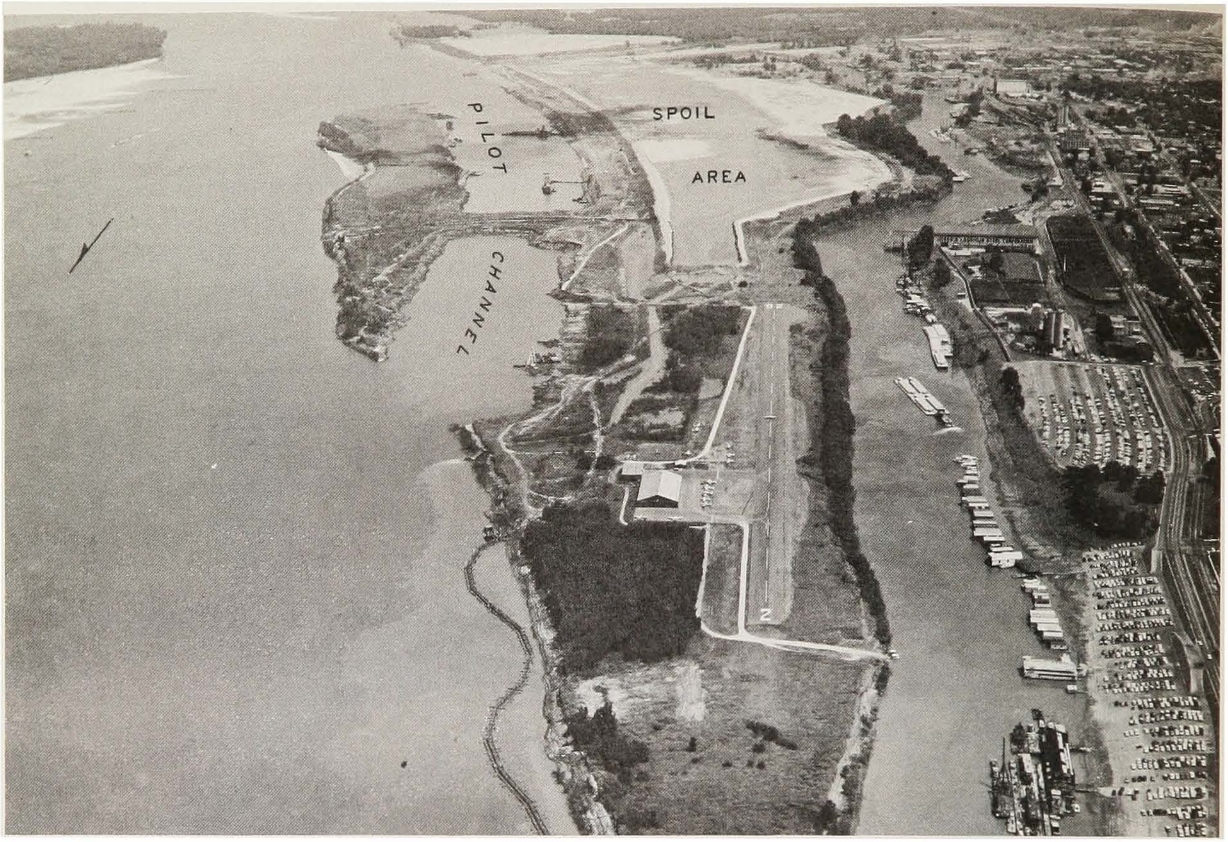


Figure 70. Dredging pilot cut for new navigation channel, Memphis

scoured out. But the natural scouring action of the river will not normally scour enough to assure sufficient depths throughout for navigation. Such crossings are dredged to authorized depths of 9 feet. Unless there are unusual local conditions, dredging is done to about 15 to 20 feet below the average low water plane. When normal bed adjustment has taken place, the effective channel depth will be from 10 to 15 feet below low water.

Descriptions of the various types of dredges used in the period from 1932 to 1972 are included subsequently under "Navigation."

Progress to date and appraisal of results

Initially, priority in the stabilization program was given to construction of revetments to control meander of the river and to reduce the amount of sand in transport. By 1972, most of the banks subject to attack that were on a favorable alignment had been protected by revetments. These revetments have successfully arrested meandering and migration of the river, thereby eliminating the necessity for levee setbacks. Most of the locations remaining to be stabilized require improvement in bank alignment before stabilization, or else are presently subject only to minor attack. Dredging has been used to improve both the alignment and channel capacity, thereby permitting construction, or advancing the time of construction, of other stabilization works. This operation will be continued in accomplishing the realignment for stabilization. Although dike construction under the channel improvement program was not started until 1956, its use as an auxiliary stabilization measure has been generally successful, despite the fact that the type most used (the permeable pile dike) has not accumulated the fill necessary for its continued effectiveness. Because of this deficiency, stone is now used entirely for new construction

and for filling existing pile structures. Contraction works are important in the improvement of the navigation channel, and in ultimately attaining the 12-foot channel. Thus, maximum acceleration of the dike program is indicated, consistent with availability of funds and construction capability.

Long-range overall programs for stabilization of the river have been formulated, revised as necessary to keep them current, and followed whenever possible. Nevertheless, immediate revetment needs and availability of funds have often dictated the time and location at which revetment would be placed. Continued efforts have been made to develop more effective revetments and to improve upon the theories and practices affecting their use. Some general conclusions may be drawn from the experience, including the following items:

a. A properly placed revetment is an effective tool for controlling the Mississippi River; hence a more extensive and intelligent use of revetment will result in more stable river conditions.

b. Many revetments that have not been properly placed have failed or have required extensive maintenance.

c. In a meandering stream such as the Mississippi, bends tend to migrate in a direction approximately parallel to the axis of the river valley; that is, north and south for the Mississippi. Revetment systems so placed as to restrict the cross-valley meandering without interfering with the downvalley migration of the bends are generally more successful than those so placed as to interfere with the downvalley migration.

d. A straight or gently curving revetment is usually more easily maintained than one located in a sharply curving bend. The straight or gently curving revetment will not usually be subjected to direct current attack, whereas at certain stages, some portions of a sharply curved revetment will very likely be under more or less severe attack.

e. The banks of a migrating bend should be stabilized by beginning at an upstream point where the banks are stable and progressing downstream. If this is not done, changes upstream may occur which will nullify parts of the work and result in undesirable alignment in the upstream portion of the stabilized section.

f. Lack of funds required for placing revetments at the time and place and in the quantities considered to be most appropriate has been the cause of higher costs for emergency work, such as levee setbacks.

g. The standard articulated concrete-mattress revetment is regarded as superior to all other types used to date, and is considered to be satisfactory from the standpoint of efficiency and cost. However, further improvement of the type or development of entirely new types, increased in effectiveness, lower in cost, and more practicable to apply, is highly desirable to assure satisfaction of future revetment needs.

Channel improvement to date has bettered navigation conditions, permitting operation of larger tows with more powerful towboats. Even though depths less than project depth are occasionally experienced for short periods of time, the maintenance of a dependable 9-foot channel has encouraged the rapid growth of commercial navigation.

Floodways

Bonnet Carré Floodway

The problems associated with design and construction of the Bonnet Carré Floodway, which is located about 30 miles above New Orleans, were attacked promptly upon passage of the 1928 Flood Control Act. As mentioned earlier, a temporary hydraulic laboratory was set up near the selected site, and tests were made to determine the most effective and economical cross section of spillway structure, probable backwater heights, type of protection against scour, and measures necessary to guard against

excessive seepage. Studies were made of foundation requirements, including resistance to sliding. A study of clearing requirements and a record of vegetation growths were made. The spillway structure, as designed, consists of a weir divided into 350 separate needle-controlled openings by piers spaced 22 feet on centers, a rear concrete apron protected by riprap, a concrete fore apron with dentiled baffles, and an articulated concrete slab talus, 6 inches in thickness, resting upon layers of riprap and gravel. The total length of clear opening is 7,000 feet, and the structure is designed for a project discharge of 250,000 c.f.s. The floodway below the spillway has a width between centerlines of side levees of 7,700 feet at the spillway structure, widening to 12,000 feet at the Lake Pontchartrain end, and its length is 5.7 miles.

Construction of the side levees began in July 1929. The spillway structure was started in August 1929 and was completed in February 1931. The side levees were raised to final grade in 1932, by which date the spillway and floodway were usable, although an agreement on the railroad crossings had not been reached and the elevated highway crossing had not been constructed. All of these crossings were completed in 1936.

Birds Point-New Madrid Floodway

High priority was also given to planning and construction of the Birds Point-New Madrid Floodway near Cairo. During Fiscal Year 1929, there were completed a topographic survey, a survey for a report on a plan to care for the drainage intercepted by the floodway setback levee, and related hydraulic studies. Preparations for construction of the setback levee were also completed. In the following fiscal year, construction of the levee and drainage ditch was started. Both items were completed during Fiscal Year 1933, but degrading of the fuseplug levees to project grade was deferred. A gap about 1,100 feet wide in the frontline levee at the lower end was left to provide an outlet for interior drainage. It also constituted an entrance for flood backwater. The Flood Control Act of 1954 authorized construction of a new levee to project grade extending from the fuseplug section of the frontline levee across the gap to the setback levee, the enlargement of 2,450 feet of adjacent frontline levee (fuseplug section) to a lower grade, and construction of a floodgate for release of interior drainage. Approximately 26,000 acres of low, unimproved land would be utilized as a sump. The 1954 act stipulated that local interests would be required to furnish all lands, easements, rights-of-way, and flowage rights; hold and save the United States free from damages; and maintain the improvements after completion. Local interests have not fulfilled these local-cooperation requirements and, accordingly, construction of the improvement has not been initiated.

The floodway modification authorized by the Flood Control Act of 1965 consists of enlargement of the frontline levee to a grade of 62.0 feet on the Cairo gage, except that the upper and lower fuseplug sections are to have a grade of 60.0 feet. In order to assure a higher degree of protection for lands in the floodway than provided under the initial authorization, the stipulation was included that the floodway will normally not be placed in operation until a flood of 60.0 feet on the Cairo gage is predicted, but the right is reserved to the United States to create artificial crevasses in the fuseplug levee or elsewhere when stages are at or above 58.0 feet on the Cairo gage and a stage higher than 60.0 feet is forecast. As of 1972, acquisition by the Federal Government of modified flowage easements is underway, and preconstruction planning for the levee construction is in progress.

Boeuf Floodway

In the period between authorization and abandonment of the Boeuf Floodway, performance of work on the project consisted principally of mapping and field surveys, activities concerned with

acquisition of flowage easements and fee simple title, and planning and design studies. Included in construction operations were concrete floodwalls along the banks of the Ouachita River in Monroe and West Monroe, Louisiana, and a levee on the east bank of the Ouachita River from a point below Bastrop to a point below Monroe. Upon abandonment of plans for the Boeuf Floodway under authority of the Flood Control Act of 15 June 1936, these works were considered a part of the Ouachita levee system.

Eudora Floodway

Plans and studies for the Eudora Floodway had been underway for several years prior to preparation of the report of the Chief of Engineers dated 12 February 1935 to the Chairman of the House Committee on Flood Control, which contains the recommendations upon which the 1936 act was based. These studies were continued up to the time of passage of the Flood Control Act of 1941, when the Eudora Floodway and its northward extension were abandoned and provisions of previous acts as to prosecution of work were repealed. No construction was performed.

Atchafalaya Floodways

The plan authorized by the 1928 act contemplated that, at times of high floods, it would be necessary to divert down the Atchafalaya Basin floodwaters in excess of the discharge capacity between the levees of the Mississippi River. This was to be done by strengthening and raising the main-river levees 3 feet for the distance necessary to assure their safety until levees at the head of the Atchafalaya Basin had crevassed. The levees on the south bank of the Red River were to be strengthened and raised sufficiently to keep floodwaters from entering the Atchafalaya Basin, except in the floodway, through the relief or fuseplug levees at the heads of the floodways. Back or guide levees were to be constructed on both sides of the basin for the major part of its length, to enclose the floodways. Existing levees on the Atchafalaya River were to be strengthened and their grades adjusted so that the productive capacity of such parts of the floodways as were not swampland would be retained during any flood of less magnitude than that of 1927.

Thus the 1928 plan provided for two overbank floodways, one east and one west of the Atchafalaya River, merging just below the latitude of Krotz Springs, near the lower end of the river levees, to form the Atchafalaya Basin Floodway about 15 miles in width. This arrangement was modified by the Overton Act of 15 June 1936 by substitution, for the floodway east of the river, of a floodway with a controlled intake on the Mississippi River north of Morganza, Louisiana (see figure 4). The control works were to be designed so that flow would not commence until the flood had reached a stage corresponding to 49 feet on the Angola gage, and would be stopped when the flood had receded to that stage. The floodway would not be operated at all unless the predicted flood should exceed the safe capacity of the leveed channels. The levees extending from this intake north along the main river and Old River to the head of the Atchafalaya were to be raised to full grade and section so as to afford additional protection to the northern end of Pointe Coupee Parish. It was believed that the Morganza Floodway would afford positive assurance that the flood-discharge capacity of the Mississippi River below Morganza Floodway would not be overtaxed, and that it would save the lands on the west side of the Atchafalaya from inundation except in extreme floods. The 1936 act also provided for improvement in the discharge capacity of the leveed channel of the Atchafalaya River and its outlets, to permit carrying the maximum amount of floodwater without increase in stages. This work included enlargement of the openings of existing railroad and highway bridges across the river. The 1928 act provided for escape to the Gulf

of Mexico of waters of an extreme flood across the comparatively high ground to the east and west of Morgan City, which was to be protected by a ring levee. In order that flood discharge to the Gulf might be more rapid, the 1936 act provided for an additional outlet west of Berwick—the Wax Lake Outlet—consisting of a dredged channel and levees with necessary highway and bridge crossings, and navigable connections with the Intracoastal Waterway. Finally, the 1936 act provided for immediate completion of the guide levees in the Atchafalaya Basin so as to afford full protection to all lands outside the floodways.

Upon passage of the 1928 act, topographic surveys, hydraulic studies, and consideration of alternative plans preceded initiation of construction. The making of numerous setbacks and strengthening of the existing Atchafalaya River levees were commenced in 1930. These levees were essentially completed to approved grade and section in 1938. However, the act of 28 June 1938 requiring that certain levees be brought to 1928 grade and section made it necessary that the east Atchafalaya River levee be enlarged. This was accomplished by 1941. For a number of years thereafter, remedial measures for both levees were required to correct minor deficiencies that developed in grade and section. In 1948 and 1949, a 13-mile extension of the west-bank levee was made. Further enlargement of the river levee was begun in 1951 and essentially completed in 1959. The grade of the west river levee is generally adequate to control floods that do not require operation of the west Atchafalaya Floodway. The grade of the east river levee is generally adequate to contain floods that do not require operation of the Morganza Floodway.

The fuseplug levee for the west Atchafalaya Floodway, located on the right or south bank of Bayou des Glaises and extending from the lower end of the Mansura Hills to Hamburg levee in the vicinity of Hamburg, Louisiana, to the center of the Louisiana and Arkansas Railway at Simmesport, was completed in 1938.

By 1935, the basin protection levees had been completed to an interim grade (generally about 6 feet below the final grade) from Palmetto to Dauterive on the west side and from Lottie to Old River on the east side. Bringing the levees up to final grade and section, as well as extending them north and south, was begun. This work was seriously handicapped during the spring and early summer of 1935 by unusually heavy rains and prolonged high water. Especial difficulty was experienced in swamp locations in the southern portion of the basin in raising and enlarging the levee to final grade and section because of slides and foundation failures during construction. By December 1937, the west-levee line furnished complete protection from Hamburg to Charenton and interim protection was furnished from a few miles below Charenton to the Verdunville Canal, and the east-levee line furnished complete protection from Viva (about 5 miles below Morganza) to Morgan City except for a navigation gap below Little Bayou Pigeon. At the same time, interim protection had been provided on the east side between Viva and Morganza, connecting the east Atchafalaya Basin protection levee to the main Mississippi River levee.

It was not until Fiscal Year 1942 that the west protection levee system was completed from Mansura Hills to the head of the Wax Lake Outlet and from Wax Lake Outlet to Berwick, except for temporary gaps left for specific requirements. By that time, the east protection levee had been completed from Morganza to Morgan City except for certain portions between Bayou Sorrel and Morgan City which were below project grade, and except for gaps at the main highway and railroad crossings and a navigation cut below Little Bayou Pigeon. In 1945 and 1946, low sections of the east and west protection levees were raised to an interim grade that would allow emergency operation of the Morganza Floodway. In 1947, permanent closure of Bayou Pigeon to a reduced grade completed the east protection levee from the Mississippi River to Morgan City except for the railroad and highway at the head of the Morganza Floodway. By 1952, it was necessary to undertake a program of levee enlargement on both the east

and west protection levee systems. The continuing problem of bringing these levees to project grade is discussed in chapter III under "Atchafalaya Basin Floodway protection levees."

Construction of the Melville ring levee was begun in 1935 and completed the following year except for a gap at the Texas and Pacific Railway crossing. In 1937, an emergency protection levee to interim grade was built around Simmesport. In 1945, the gaps in the Simmesport and Melville ring levees were either completely closed, or so narrowed that closure could be effected quickly. In 1947, the gated Brushy Bayou Outlet in the Simmesport ring levee was completed. The Krotz Springs ring levee was constructed in 1956 and 1957.

Development in the urban areas of Berwick and Morgan City and vicinity did not permit economical use of levees for local flood protection, and consequently concrete floodwalls were provided. The Berwick wall (1 mile in length) was completed in 1949. The Morgan City wall (1.3 miles) and the Tiger Island wall (0.4 mile) with levee extension were completed in 1948 and 1954, respectively. Pumping plants were constructed for removal of interior drainage behind the Morgan City and Tiger Island protection when necessitated by high river stages, and a drainage canal was constructed to convey the Berwick interior runoff into the Wax Lake East area.

Subsequent to Fiscal Year 1955, nearly 7 miles of revetment have been placed on the Atchafalaya River banks. Stabilization works, consisting of a subaqueous articulated concrete mattress and riprap upper-bank pavement, have been placed at five locations on the upper 20 miles of the river. At these locations, above and below Simmesport, active bank caving had been seriously threatening the controlling levee and causing poor channel alignment. In addition to the upper river placement, similar revetment, supplemented by subaqueous riprap pavement, was placed in Fiscal Year 1968 at the Morgan City front where caving and bank recession had taken place. Substantial bank movements occurred in 1959 and 1962 near the north end of the Morgan City floodwall. Further failures would have required relocation of the wall with resulting severe economic loss to the city. Placement of an additional 21 miles of bank stabilization, needed to protect existing structures and maintain a favorable stream alignment, is planned.

Substitution of the Morganza Floodway for the east Atchafalaya Floodway, as stipulated by the 1936 Overton Act, required selection of a location for the Morganza upper guide levee. The route chosen in 1937 extended from a point on the Mississippi River near Batchelor to the east Atchafalaya River levee about 2 miles upstream from Melville. The purpose of this levee is to protect more than 100 square miles of productive farmlands in upper Pointe Coupee Parish from inundation during operation of the floodway. Construction of the levee, excluding gaps left for railroad, highway, and bayou crossings, was completed in 1940. The lower guide levee extends about 19.4 miles in a southerly direction from a point on the Mississippi River levee near Morganza to join the east Atchafalaya Basin protection levee at the latitude of Krotz Springs, and thus it was a segment of the east Atchafalaya Basin protection levee prior to creation of the Morganza Floodway. Concurrently with construction of the upper guide levee, enlargement of the lower guide levee was prosecuted vigorously and was completed in 1940 except for a gap at the railroad and highway crossing near Morganza. The two guide levees form a floodway averaging about 5 miles in width.

The Overton Act provided for construction, at United States expense, of three railway and two highway crossings over the Morganza Floodway. The single track Port Allen branch of the Texas and Pacific Railway and Louisiana State Highway No. 1 traverse the floodway near its head. Agreements were reached to place them on a common embankment and upon the authorized control structure, located centrally in the floodway. In 1942, concurrently with initial planning for all Morganza high-level crossings,

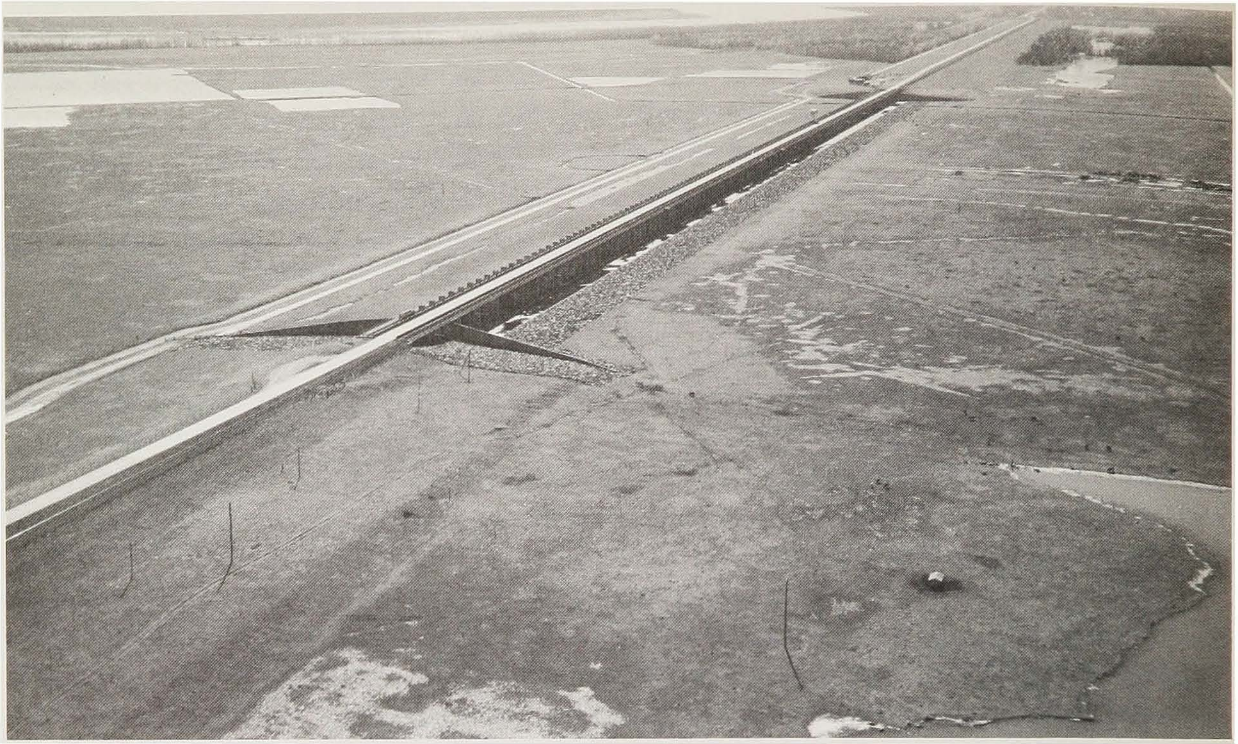


Figure 71. Morganza Control Structure, Louisiana

pile tests, to be used as a basis for the foundation design, were started. The control structure (figure 71) is of reinforced concrete with 128 gated openings, each 28 feet 3 inches wide, separated by 3-foot piers. Each opening is equipped with a steel vertical-lift gate and there are two gantry cranes on the structure for operation of the gates. The piers support bridges for the gantry crane, the highway, and the railroad track. The railway crossing was placed in service late in 1952, and clearing of the forebay in the vicinity of the structure was completed a few months later. The control structure was completed and operable early in 1953; only permanent paving of the highway approaches and other deferred construction as provided under the reimbursable contracts remained to complete the structure. Degrading of the forebay levee was completed in August 1955. A lump-sum payment was made early in 1960 to the State of Louisiana, Department of Highways, to provide for permanent pavement on completing the highway relocation at a later date, thereby permitting utilization of the maximum life of the temporary paving. The highway relocation has now been completed.

The additional outlet to the Gulf of Mexico west of Berwick authorized by the 1936 act—the Wax Lake Outlet—was designed to have a capacity of 270,000 c.f.s. in order to divert floodwaters out of the basin, thereby reducing flood heights and, during extreme floods, protecting the cultivable lands along the Teche and Boeuf Ridges and vital transcontinental communication routes at the latitude of Morgan City. The channel was located about 10 miles west of Berwick, extending from Six Mile Lake through the Teche Ridge and Wax Lake into Atchafalaya Bay, a distance of about 15.7 miles. From Six Mile Lake to a point one-half mile below Bayou Teche, the channel has a bottom width of 300 feet. Below that point, the bottom width is 400 feet. The channel has a uniform depth of 45 feet below mean sea level. Excavation started in November 1937 with dredging to project depth, but to half the project width from Six Mile Lake to the lower end of Wax Lake. Dredge spoil was used to build the west guide levee. A plug about 1,200 feet in length was left at the site of the highway and railroad

crossings, to be removed when the bridges had been constructed. Construction of the fixed bridges to carry U. S. Highway 90 and the Texas and New Orleans Railroad (Southern Pacific Lines) across the outlet was completed and the facilities were placed in operation in 1942. Excavations for the navigation crossover for the Intracoastal Waterway and for the remainder of the outlet channel extending from Wax Lake to Atchafalaya Bay were also completed in 1942. Removal of the plug left underneath and adjacent to the railroad and highway crossings was finished in 1943.

In addition to relocation of these crossings, operations necessitated by excavation of the Wax Lake Outlet included enlargement of the east and west spoil banks to guide levee project grade and section, adjustment of telephone line, powerline, and gasline crossings, and construction of the Calumet floodgates. These floodgates are located in the east and west outlet guide levees at the crossings of Bayou Teche. Their function is to provide for navigation in Bayou Teche and to enable floodflows to be regulated. The reinforced concrete floodgates have 45-foot clear widths with sills 9.8 feet below mean sea level, and are equipped with steel sector gates. They were finished in 1950.

Besides the railroad and highway crossings over the Morganza control structure, previously mentioned, two more railroad crossings and one more highway crossing over the Morganza Floodway were authorized by the 1936 Flood Control Act, and, in addition, there were authorized one railroad and one highway crossing over the west Atchafalaya Floodway.

The routes of the New Orleans, Texas, and Mexico Railway (Missouri Pacific system) and of U. S. Highway 190 extend from Lottie to Courtableau, crossing both floodways. The elevated single-track railway crossing provides the means for maintaining uninterrupted traffic when either of the floodways is operated. In lieu of providing two additional high-level crossings of the west Atchafalaya Floodway for the Texas and Pacific and Kansas City Southern Railways, the Opelousas-Ville Platte-Bunkie railway connection, located west of the west Atchafalaya Floodway between Opelousas and Bunkie, was constructed. When the floodway is in operation, traffic on these two railway lines will be detoured over the New Orleans, Texas, and Mexico high-level crossing of both floodways, and to or from their respective tracks by way of the connection. Construction of the railway crossings, consisting of reinforced-concrete ballasted deck-type trestles and earth embankments, as well as construction of the railway connection, was completed in 1961. The high-level crossing for U. S. Highway 190 consists of paved embankments and a reinforced-concrete bridge supported by concrete piling. The elevated four-lane roadway, averaging 29 feet in height above natural ground, will provide the only usable east-west highway route during floodway operation between U. S. Highway 90 through Morgan City, 60 miles to the south, and U. S. Highway 84 through Natchez, 74 miles to the north. Construction was begun in 1956 and completed in 1965.

The fifth authorized crossing is that of the single-track Texas and Pacific Railway main line over the Morganza Floodway between McKneeley and Red Cross. Although this line also traverses the west Atchafalaya Floodway from Melville to Palmetto, this portion was not included in the authorization. The use of this floodway will be required during major floods estimated to occur less frequently than once in 200 years. During such use, traffic is to be detoured as described above. The crossing, consisting of reinforced-concrete deck girder trestles and earth embankment sections, was completed in 1950.

Among other major modifications or adjustments of railway and highway facilities required in the Atchafalaya Basin was that of the combination bridge over the river at Simmesport, owned jointly by the State of Louisiana and the Kansas City Southern Railway, which, in connection with improving the discharge capacity of the channel, was lengthened by addition of two 300-foot steel spans on the west side of the river. The work was completed in 1938. In the following year, the Missouri Pacific

Railroad Bridge at Krotz Springs was modified by constructing deep piers and other foundation strengthening and by extending the bridge 721 feet on the west side of the river as a necessary preliminary to increasing the channel capacity by dredging. The planned diversion of additional floodwaters through the basin was considered to endanger the stability of the Southern Pacific Railroad Bridge over Berwick Bay between Morgan City and Berwick. Accordingly, in 1942 the bridge was raised 4 feet, bringing the low steel above all but the design flood height.

Pipelines, communication lines, and other utilities were required to be relocated across the floodways. Removal of bodies from a number of cemeteries and reburial at new sites were also necessary.

On completion of the basin guide levees, restoration was required of the drainage and navigation routes intercepted by the levee construction. On the west side, this included enlargement of the levee borrow pits and adjacent streams, construction of additional diversion channels and interceptor ditches, and construction of culverts and sublevees. Bayou Darbonne drainage structure was constructed in 1941 to restore the connection of Bayou Courtableau with the normal backwater of the west floodway and to provide additional water for rice irrigation in the Teche and Vermilion basins. In order to retain and divert the low water flow of Bayou Courtableau into Bayou Teche for irrigation, control structures, consisting of wide, shallow-flow weirs, were constructed in 1942 on the south bank of Bayou Courtableau west of the levee. Floodflows pass over the weirs into the borrow pit below, through outlet channels excavated below the weirs. In 1956, the Courtableau drainage structure and channels were completed. This gate-controlled feature, located about 2 miles southeast of the village of Courtableau, is designed to permit diversion of a portion of the floodflows through the west protection levee into the floodway. Another major feature on the west side is the Charenton drainage and navigation canal, together with the Charenton floodgate. The canal extends from the protection levee to Bayou Teche, thence along the bayou and a land cut to West Cote Blanche Bay. The floodgate provides an outlet for the intercepted drainage carried by the west basin protection levee borrow pit, and also serves as a navigation connection between Grand Lake and the drainage canal. On the east side, the drainage of Pointe Coupee Parish above the Morganza Floodway, which was interrupted by construction of the upper Morganza guide levee, was restored by construction of the Pointe Coupee drainage structure, located at the intersection of Bayou Latenache and the guide levee, and enlargement of the bayou from the drainage structure to U. S. Highway 190. This feature was completed in 1942. Drainage intercepted by the east Atchafalaya Basin protection levee was restored by enlarging portions of the borrow pit and nearby streams. From the navigation gap left in the levee near Little Bayou Pigeon to Bayou Long, the floodwayside borrow pit was enlarged to dimensions (9 by 100 feet) required for its use as a portion of the Intracoastal Canal. Restricted sections of the landside borrow pit between a point just south of Lottie and Bayou Maringouin were enlarged in 1940. Landside of the east protection levee, existing streams from the navigation gap in the levee (later the site of Bayou Sorrel Lock) to the vicinity of Lake Palourde were improved; a land cut was made around the east side of Lake Palourde to Bayou Boeuf; and Bayou Boeuf was enlarged to provide a minimum channel of 9 by 100 feet for drainage and navigation. This feature was completed in 1947. Although the landside route is about 22 miles longer than the project route between Port Allen and Morgan City, it will afford easier navigation in times of flood and swift currents. Also, during times of low rainfall east of the levee, fresh water may be passed through Bayou Sorrel Lock into the channels east of the levee.

Bayou Sorrel Lock, previously described as necessary to provide a navigation connection through the east protection levee for the Morgan City-Port Allen route to the Gulf Intracoastal Waterway, was completed in 1951. It has a usable length of 797 feet, a clear width of 56 feet, and a 15-foot depth

over the sills at mean low water. Berwick Lock, located in the west protection levee near its crossing of the lower Atchafalaya River about 2 miles north of the town of Berwick, affords a navigation passage through the levee and permits navigation of the lower Atchafalaya River to Patterson and to Bayou Teche. Completed in 1951, it has a usable length of 300 feet, a clear width of 45 feet, and sills 9.8 feet below mean sea level. Bayou Boeuf Lock, located in the east Atchafalaya Basin protection levee below Morgan City at a point where it crosses Bayou Boeuf and the Intracoastal Waterway, provides for navigation through the levee which protects the areas and communities east of Morgan City from floodwaters of the Atchafalaya Basin. The lock has a length of 1,156 feet, a clear width of 75 feet, and a depth over sills of 13 feet at mean low Gulf level. It was completed in 1955.

Due to the increased stages and longer duration of flooding expected to be experienced during major floods as a result of the proposed operation of the Atchafalaya Basin Floodway, provision of flood control for an area west of Berwick was needed. The area, which is low-lying with elevations ranging from 1 to 10 feet, mean sea level, was subdivided into nine separate units designated as Bayou Yokely, Franklin, Centerville, Maryland, North Bend, Ellerslie, Gordy, Wax Lake West, and Wax Lake East. Seven of these units are adjacent to Bayou Sale Ridge and Bayou Teche Ridge, and the other two are adjacent to Wax Lake Outlet. Interior drainage provided by local interests consists mainly of open ditches and canals which carry the runoff to landside borrow pits for levees which, in turn, convey flows to floodgate and pumping station sites. Each area was provided a pumping plant and one or more gated culverts or other drainage structures. An inverted siphon was constructed under Bayou Teche at the approach channel to the east Calumet floodgate to assure adequate drainage of the portion of the Wax Lake East area located north of Bayou Teche, and to permit higher stages in Bayou Teche with less frequent operation of the Berwick Lock and the east Calumet floodgate. Planning of this feature was begun in 1949, but construction was not completed until 1964. Portions of the levees protecting the Wax Lake East and West areas are not yet completed to adopted grade and section.

Pursuant to the 1936 act, which provided for improvement of the discharge capacity of the leveed channel of the Atchafalaya River and its outlets, dredging in constricted reaches between Simmesport and Melville was begun in 1936. When the railroad bridges at Simmesport and Krotz Springs, previously described, had been lengthened in 1940, the river cross section was increased by dredging along the west bank. In 1941, dredging was performed in constricted reaches between Red River and Alabama Bayou. This improvement dredging feature of the project was continued from year to year until the end of Fiscal Year 1955, when it was considered to be completed.

Dredging to provide a continuous main channel through the central portion of the Atchafalaya Basin for the purposes of increasing the flood-carrying capacity of the basin and of lowering flood heights has also been performed over many years when favorable river stages prevailed. The dredging reach extends from the lower end of the leveed channel at Alabama Bayou entirely through Grand River and Six Mile Lake to Wax Lake Outlet and Morgan City. Initial operations in 1933 utilized limited plant to do experimental dredging. The work was soon greatly expanded and, in 1949, a total of 17 dredges removed 29,500,000 cubic yards of material at a cost of $2,400,000. Development of a single main channel required closing numerous distributary channels and progressively increasing the project channel area. The initial goal of a 40,000-square-foot channel area was achieved in 1968. Present efforts are directed toward a 60,000-square-foot channel. Future goals are successively an 80,000- and a 100,000-square-foot channel, and the target date for completion is Fiscal Year 1985. The estimated total cost, including adjustments of pipeline and utilities, is $112,600,000.

In 1967 and 1968, navigation channels were dredged in the Atchafalaya Basin for access purposes,

extending eastwardly from mile 78.5 of the central channel and westwardly from mile 77.3, thus providing access between the east and west floodway areas. They are used by both commercial and recreational craft. In addition, channels for fresh-water distribution during seasons of low water were established from the central channel eastward via Little Tensas Bayou and upper Grand River, and westward via Bayou La Rompe, Lake Long, and Bayou L'Embarras. The intermittent overflow from these channels is considered to be beneficial to fishing and hunting activities in the area.

The Atchafalaya Floodway is recognized as a fish and wildlife area of national significance. To mitigate fish and wildlife losses due to the project construction, provision has been made for future construction of two fresh-water control structures with cross-basin channels. One will be located in the east Atchafalaya River levee in the vicinity of Sherburne, and one in the west Atchafalaya River levee in the vicinity of Bayou Courtableau. These structures are planned to supply fresh water from the Atchafalaya River to the marshlands on both sides of the river.

Despite the existence of recreation facilities in the basin that have been provided by local interests, such development is considered to be far below the area's potential. Accordingly, a preliminary master plan for public access and recreational use of the basin has been prepared by authority of the Flood Control Act of 1944, as amended by the Flood Control Act of 1962, under which the Chief of Engineers is authorized to construct, maintain, and operate public park and recreational facilities at water resource development projects under control of the Department of the Army. The master plan contemplates provisions for the satisfaction of basic recreational needs of 500,000 visitors annually, and includes facilities for access, parking, boating, hunting, and fishing. Under the preliminary plan, public access and recreation are to be provided at 11 locations along the east Atchafalaya Basin protection levee between Ramah and Morgan City; at 12 locations along the west Atchafalaya Basin protection levee between Bayou Courtableau and Berwick; and at 3 midbasin areas. Planning is in progress in 1972, but construction has not begun.

Backwater Areas

Backwater areas occur when floodwaters are confined between levee lines on both banks of the Mississippi River and a gap exists in a levee line to allow outflow from a tributary stream to pass. The principal backwaters on the lower Mississippi River are the St. Francis, the White-Arkansas, and the Red on the west bank, and the Yazoo on the east bank. Lesser backwaters occur at the mouth of the Ohio and in the lower reaches of the small tributaries on the east side of the main river. In time of flood, the backwater extends upstream behind the end of the main-line levee and on up into the tributary basin. The area then submerged depends upon both the stage of the flood confined by the main-line levees and the volume of discharge of the tributary. The main-line levees protect the backwater areas from Mississippi River floodwaters that otherwise would flow down overbank from upstream, but by confining greater floods, these levees have increased the backwater areas and the depths of inundation. The Mississippi River Commission has consistently opposed the exclusion of great floods from the large backwater areas because elimination of the backwater storage capacity would materially increase flood heights. However, partial protection of the better portions of such areas is considered unobjectionable, provided the areas are restored to their normal function of storing floodwaters during great floods.

St. Francis River backwater area

The expanded program of levee and drainage improvements and channel rectification in the St. Francis Basin, adopted by the Flood Control Act of 1950, included construction of a continuous levee below Marked Tree, along the left bank of the realigned St. Francis River, to a fuseplug levee about 9 miles in length joining the left bank levee to the Mississippi River main levee near Whitehall. This levee will protect an additional 790 square miles from overflow by backwater of the Mississippi River, except when floods on the Mississippi approach the magnitude of the project design flood and overtop the fuseplug section. However, the backwater area will be protected against all St. Francis headwater flooding. The protected area will continue to drain into the St. Francis River by means of a 12,000-c.f.s. pumping plant and floodgate to be located in the extreme lower portion of the area. A substantial length of the lower St. Francis River will be relocated, after which the old channel will function as a drainage collector and sump for the protected area. The fuseplug section will permit flood control storage of Mississippi River floodwaters in the backwater area during the possible occurrence of the project design flood. A pumping plant and floodgate are also to be provided at Madison for evacuation of interior drainage during high river stages.

Of the 156.7 miles of authorized east-bank levee, 150.8 miles have been constructed to project grade and section. Construction of the pumping facility, which has been officially named the W. G. Huxtable Pumping Plant, has been initiated by contracting for the furnishing of equipment and machinery. Completion of the floodway levee, the fuseplug levee, floodgate, and appurtenances is scheduled to be undertaken as rapidly as permitted by availability of funds.

White River backwater area

Congress concurred in the general principles affecting backwater areas in the act approved 15 June 1936 by authorizing protection of a portion of the White River backwater area from all but the larger floods by an extension of the frontline levee system up the east side of the White River, thence to a connection with the main-line Mississippi River levee near Old Town Lake. This extension of the levee system for protection of the backwater area was constructed in two operations. The initial levee construction was carried to an interim grade in order to obtain substantial protection quickly. This phase was begun in 1938 and included two fuseplug sections composed, in part, of sand to insure control of points of entry of floodwaters into the backwater area. The Little Island Bayou and Deep Bayou drainage structures were provided to permit drainage of impounded runoff normally and to furnish a means of lowering the pool below the fuseplug level when required. Construction of the structures was completed in 1940. The levee was brought to interim grade the following year and completed to full grade and section in 1960. The levee, about 40 miles in length, together with the main-line Mississippi River levee between Oldtown and Laconia Circle, protects the interior against all but very large floods, and makes possible a reduction of extreme crests on the White River by admitting floodwater into the enclosed area.

The Flood Control Act of 1958 authorized the additional installation of a 1,500-c.f.s. pumping station for flood control and drainage, to be constructed adjacent to the Little Island Bayou outlet structure. The station can be used to evacuate impounded runoff during periods when White River stages do not allow gravity drainage. The act also modified operation of the Little Island Bayou structure to provide for controlled stages in the sump area for the benefit of fish and wildlife management within

the area enclosed by the backwater levee system. Construction of a pumping station, officially designated the Graham Burke Pumping Plant, was commenced in 1962 and completed in 1965.

Yazoo River backwater area

The Yazoo River backwater area in west-central Mississippi lies between the east bank of the Mississippi River and the hills (see figure 5). It extends northward some 60 miles to the latitude of Hollandale and Belzoni. An area of about 1,280 square miles is subject to flooding from the Mississippi River by backwater through the opening between the end of the partially completed backwater levee and the hills immediately north of Vicksburg. The Flood Control Act of 1941 provided for about 54 miles of levees along the west bank of the Yazoo River below Yazoo City and enlargement of 7 miles of existing levees in the Rocky Bayou area on the east bank below Yazoo City. The drainage impounded by the backwater levees would be evacuated by means of culverts and floodgates when river stages outside permitted, and would be stored in sump areas or pumped over the levee when gravity drainage was not possible because of Mississippi River or Yazoo River floods. The act of 1944 authorized the Chief of Engineers, at his discretion, to add to the project 38 miles of levee in the Satartia area and the Satartia area extension, both on the east side of the Yazoo River below the Rocky Bayou area. Subsequent to the 1941 act, the Lower Auxiliary Channel (later named the Will M. Whittington Auxiliary Channel) was incorporated as a feature of the Yazoo Headwater Project. It divided the backwater area west of the Yazoo River into two parts—the Yazoo and the Carter areas.

The Yazoo backwater levee overtopping grade, elevation 107.0 feet, is 2 feet below the 1956 Mississippi River project flow line. The levee grade will provide protection from all floods of record, but would be overtopped by the Mississippi River project flood, a provision that is necessary to maintain the integrity of the main-line Mississippi River levees. The estimated frequency of overtopping is about once in 200 years.

Studies made during preparation of the report contained in House Document No. 308, 88th Congress, found that channel improvements in the Mississippi River, as well as reservoirs and associated works in the upper Yazoo River Basin, constructed since the backwater plan was initially prepared in 1939, had materially reduced the frequency and duration of flooding in the backwater area. Consequently, it was possible to eliminate the pumping plants from the plan and to substitute gravity drainage at a substantial saving in cost. The change in plan added about 20 miles of channel required to connect the Big Sunflower River and Steele Bayou sumps with the main outlet at Steele Bayou. Restudy of the Carter, Rocky Bayou, and Satartia areas showed that pumping plants could not be justified but that plans for levees with gravity drainage were practicable. It was also found that the authorized extension of the Satartia area levee to protect additional land was not justified.

The Yazoo area, lying west of the Will M. Whittington Auxiliary Channel and the lower reach of the Yazoo River, comprises about 82 percent of the entire backwater area. The Big Sunflower and Little Sunflower Rivers, Deer Creek, and Steele Bayou flow through this area. About 30.5 miles of levee will be required between the lower limits of the Mississippi River east-bank levee and the west levee of the Auxiliary Channel. Construction was begun in 1948 when a short segment of levee that coincided with the alignment of U. S. Highway 61 was built by agreement with the Mississippi Highway Department. Further construction was not undertaken until 1960. About 12 miles of the lower end of this levee have been completed. In addition, 8 miles of connecting channel between the Steele and Sunflower sumps have been completed. The Steele Bayou drainage structure, begun in 1965, was completed in 1969. Construction has not started on the Little Sunflower drainage structure.

The Carter area, lying east of the Auxiliary Channel and west of the Yazoo River, comprises about 161 square miles of delta lands which are to be protected from extreme floods by a levee 29.3 miles in length, extending from the lower terminus of the east-bank Auxiliary Channel to a connection with the existing Yazoo River headwater levee opposite Yazoo City. Interior drainage will be carried through a new channel connecting Lake George to a drainage structure for evacuating these waters through the levee. Construction in this area has not started.

The Rocky Bayou area lies east of the Yazoo River between the latitude of Yazoo City and Satartia. It comprises about 22 square miles of alluvial land to be protected from extreme floods. The existing levee is to be enlarged to project grade and section, the interior drainage system will be improved, and a larger capacity floodgate will be constructed to replace the existing structure. Construction has not yet started in this area.

The Satartia area comprises about 26,700 acres of alluvial lands just south of and including the town of Satartia. The protection will include a 19.4-mile levee and a drainage structure to evacuate interior drainage for the protected area. Part of the levee will be constructed to the overtopping grade of elevation 107.0 feet. No construction had been performed in the area by 1972.

Red River backwater area

Prior to construction of the Red River backwater levee, the backwater area functioned as a pool or distributary basin for floodwaters. During minor floods, it usually received inflows from the Mississippi, Red, Ouachita, Boeuf, and Tensas Rivers on the rise, and temporarily stored such portions of them as the Atchafalaya River could not discharge at the pool levels successively attained. In great floods, under the project plan existing prior to 1941, the area would receive inflows from these sources until the pool level had attained an elevation at the head of the west Atchafalaya Floodway sufficient to cause flow over the fuseplug levee, after which the outflow would be distributed between the floodway and the Atchafalaya and Mississippi Rivers.

Because the Red River backwater area is broken up into small units by streams too large to interrupt, it cannot be protected substantially in its entirety as was done in the case of the Yazoo backwater. The plan for protection of the Tensas-Cocodrie area, authorized by the 1941 Flood Control Act, involved extension of the Mississippi River levee at full grade from Deer Park (where in 1941 the gradeline dropped to the 1914 grade) to Black Hawk (see figure 6). From that point, a levee would be extended west to the Black River near Acme and thence westward and northward up the Black River to Jonesville. Above Jonesville, the levee would follow, generally, the left bank of the Tensas River to the Tensas-Concordia Parish line, thence eastward to the Mississippi River levee near the upper end of Lake St. John. The overtopping grade of the Tensas-Cocodrie area levee was set at an elevation to correspond to a stage 4 feet below the main Mississippi River levee grade at Red River Landing. The overtopping levee grade elevation from Black Hawk to Acme is 59.8, and the gradeline slopes from this point to elevation 60.8 at the latitude of Monterey. The estimated frequency of overtopping is about once in 100 years. Above Monterey, the Tensas-Cocodrie levee grade has a 1-foot freeboard above the 1956 project design flow line meeting the 1945 Red River crest stage, or the 1927 crest with Morganza Floodway operating. The plan made provision for intercepted drainage, including a drainage structure at Bayou Cocodrie and a sump area of 142,300 acres. The levee, with a length of 93.1 miles, together with 2.1 miles of high ground, provides protection for 209,000 acres of rich alluvial land from all floods of record, but would be overtopped by the Mississippi River project flood. The pumping plant, authorized by the 1965 Flood Control Act to be constructed in the vicinity of Bayou Cocodrie drainage structure, was

planned to lower the elevation and shorten the duration of flooding within the interior sump area during times of high water on the Red and Mississippi Rivers.

Although plans and studies of the Red River backwater levee were in preparation in 1943, the start of construction was delayed by wartime restrictions requiring conservation of manpower and materials. The first placement of levee fill began in 1947. This construction continued for several years at varying rates, and in 1953 enlargement of previously constructed levees to adopted grade and section, as well as ditch excavation and other drainage work, was started. Construction of the Bayou Cocodrie drainage structure was finished in 1952, and the levee was completed to approved grade and section in 1954. No construction has been performed on the Bayou Cocodrie pumping plant or the fish and wildlife features authorized by the Flood Control Act of 1965.

Additional levee improvements in the Red River backwater area for partial flood protection of three areas were recommended in the comprehensive review of the Mississippi River and Tributaries Project incorporated in House Document No. 308, 88th Congress, 2d session, under authority of the Flood Control Act of 1941. The improvements comprise loop levees, with drainage structures to evacuate interior drainage. The Larto Lake to Jonesville area, formerly a single area, was divided into two parts by the diversion channel from Catahoula Lake to Black River, being constructed as a feature of the Ouachita and Black Rivers 9-foot navigation project. The levee in the upper area will be about 58 miles long and will enclose 102,000 acres. The levee in the area below Larto Lake will be about 20 miles long and will enclose 8,400 acres. Construction was initiated in 1965 and is not completed. The levee for the Sicily Island area, with a length of 59 miles, will begin near Sicily Island, Louisiana, and extend southward down the west side of the Tensas River, then northward up the east side of the Ouachita River to tie into high ground opposite Harrisonburg, Louisiana. It will protect 73,000 acres. Construction has not started. The feature entitled "South of Red River Area" will involve extension of the existing south-bank Red River levee along the east side of Lake Long to the alignment of the authorized Overton-Red River Waterway, then along the north bank of the waterway to high ground near Marksville. This levee will protect 37,800 acres. Construction has not begun.

The 1965 act authorized the estimated first cost of fish and wildlife mitigation measures, consisting of acquisition of 12,800 acres and construction of roads, parking area, and boat-launching facilities in the Larto Lake to Jonesville and Sicily Island areas. Development of this feature is contingent upon completion of the levees for the respective areas.

Tributary Basins

General description

The Alluvial Valley of the lower Mississippi River—that portion of the basin that was overflowed by the river in its natural state—is bounded by continuous escarpments except where tributary streams enter the main river. The basins of some of the smaller tributaries are wholly or almost wholly in the Alluvial Valley, and accordingly are included entirely in the Mississippi River and Tributaries Project. The largest of these tributaries are the St. Francis and Yazoo Rivers. The basins of the major tributaries of the lower river, of which the largest are the Red and Arkansas Rivers, are largely outside the Alluvial Valley except for lowlands near the confluence with the Mississippi, which are subject to backwater inundation during extreme floods. In general, the limits of the effects of Mississippi backwater mark the upper boundaries of the area included in the project.

In most of the tributary streams, problems of flood control and drainage are inseparable. The first objective of local interests was to drain the highest lands. This led to creation of swamp sumps in the lower areas along the main interior channels, and to obstruction of the stream channels. Provision of adequate channel capacity was required to assure drainage of upstream areas, and measures to prevent overflow of the low areas were also needed. The increased channel capacity has been obtained by enlarging and straightening channels, by constructing levees to confine overbank flows, and, in some instances, by means of auxiliary channels. As development of the basins continues, extensions will inevitably be needed. In addition, reexamination will be needed of those studies that concluded that economic justification was lacking.

Cairo, Cairo Drainage District, Mounds, and Mound City

The communities of Cairo, Mounds, and Mound City, with adjacent agricultural lands, are located in southern Illinois above the confluence of the Mississippi and Ohio Rivers. They are protected by 20 miles of levee and floodwall extending from high ground near the Cache River on the Mississippi River side above Cairo to high ground on the Ohio River above Mound City. The initial flood protection, including pumping plants in the city and at Goose Pond in the Cairo Drainage District, was constructed by local interests. Under provisions of the Flood Control Act of 1928, as amended, the Flood Control Act of 1938, Public Law 685 of the 84th Congress, and emergency flood control authority, the Federal Government has improved that protection. Cache River, which formerly emptied into the Ohio River just above Cairo, was diverted to join the Mississippi above Cairo. The former Cache channel remaining in the protected area is used for ponding of storm drainage during periods of high stages on the Ohio. At low stages, the stored runoff is drained through a floodgate into the Ohio. A pumping station at this site, to be constructed under authority of the 1938 act, has not been built; nor have the drainage channels, authorized by the 1965 Flood Control Act to convey runoff from the Mound City area to the Cache pumping plant. A levee closure below Mound City, levee improvements at and above Mound City, and a new levee along the Cache River diversion channel at the upper end of the Cache Drainage District, raising the protection to project flow-line grade, were completed in 1950. A 50-c.f.s. pumping station to serve the Cottonwood Slough area of the Drainage District was completed in 1964. Although not constructed as a feature of the Mississippi River and Tributaries Project, it provides an outlet during high river stages for interior runoff from about 4,620 acres protected by the Mississippi River levee system.

Because of space limitations, a masonry floodwall rather than a levee was initially constructed for flood protection along the Ohio River side of the city of Cairo. The wall, about 3 miles in length, consisted of several types of sections, including cantilever, counterfort, and gravity, constructed in 1914 to a grade elevation of 60 feet on the Cairo gage. It was strengthened in 1935 by constructing, alongside and adjacent thereto and to the same grade, a concrete cellular wall filled with earth. Revision of the project grade in 1941 required raising the wall by amounts varying from 4.6 feet at the lower end to 6.2 feet at the upper end. In general, the increased height was obtained by a vertical extension of the existing cellular wall, forming a reinforced concrete cellular wall box which was then filled with earth. The wall construction was completed in 1950.

The levee and floodwall on the Ohio River portion of the improvement were constructed as a part of the Ohio River Basin Project. The completed levee was transferred from the Louisville District to the Memphis District in 1952. Subsequent to the transfer, the levee side slopes were modified, as a

feature of the Mississippi River and Tributaries Project, to conform to the standard Mississippi River levee.

Construction has not yet been undertaken on the pumping plants and other drainage facilities in Cairo and vicinity, authorized by the Flood Control Act of 1968.

St. Johns Bayou, Missouri

St. Johns Bayou, a partially improved natural channel and right-bank tributary of the Mississippi River, drains an area of about 480 square miles in southeastern Missouri. It provides the outlet for the many natural and artificial channels that form the drainage system for the basin, including the landside intercepting ditch along the setback levee constructed as a part of the Birds Point-New Madrid Project. The drainage area is bounded on the west by Sikeston Ridge. Prior to 1927, local interests, with Federal aid, constructed the New Madrid-Sikeston Ridge levee for protection of the southwestern part of the area against floodwaters of the Mississippi River. Under the Flood Control Act of 1928, this levee was raised and enlarged, and the setback levee was constructed to form Birds Point-New Madrid Floodway. A 4,200-foot gap between the downstream end of the setback levee and the New Madrid-Sikeston Ridge levee permitted Mississippi River backwater to enter and flood the lower St. Johns Bayou area. Protection of the lands in this area, authorized by the Flood Control Act of 1946, included enlargement of the lower 17 miles of the floodway setback levee, and construction of a new levee extending from the setback levee across St. Johns Bayou to the Sikeston Ridge levee, with a floodgate at the bayou crossing. Construction of the floodgate, consisting of six 10- by 10-foot reinforced concrete barrels controlled by six power-operated lift gates at the outlet end, was started in 1949. The levee and structure were finished in 1953. Completion eliminated further need for that portion of the New Madrid-Sikeston Ridge levee north of its junction with the new closure levee as a means of protection against Mississippi River floods. Drainage from the area west of the New Madrid-Sikeston Ridge levee, which formerly reached the Mississippi River through the borrow pit east of the levee, was intercepted by the closure levee. Construction of a ditch from the borrow pit to St. Johns Bayou opposite the north edge of New Madrid provided a new outlet for that drainage.

St. Francis and L'Anguille

The watershed of the St. Francis River, including the L'Anguille River Basin, is in southeast Missouri and northeast Arkansas. It is about 215 miles long with a maximum width of 53 miles, and comprises about 8,400 square miles. In the lower basin, Crowleys Ridge forms the divide between the L'Anguille and St. Francis River watersheds. The Commerce Hills lie to the north of the Little River Basin, which is the principal tributary watershed. The Mississippi River main-stem project levee protects the flood plain from high Mississippi River stages.

At the time of adoption of the Mississippi River and Tributaries Project by the 1928 act, local interests had organized into more than 50 drainage and levee districts and had spent about $20,000,000 constructing over 2,000 miles of ditches and 200 miles of levees. These facilities permitted reclamation of large areas of the highest lands. This, in turn, caused increased rates of runoff, resulting in flows that exceeded the capacity of the outlet ditches and flooded the lower lands. Some of the levees were inadequate and were crevassed by the larger floods. The principal problems resulted from the uncontrolled runoff from the Ozark Highlands and the inadequate levees constructed by local interests along the river to contain the floods. The lower portion of the basin was subject to both headwater and backwater

floods. The tributary streams and many of the drainage facilities constructed by local interests were inadequate to carry the runoff.

The basic plan for flood protection of the St. Francis Basin, authorized by the act of 1936, provided for Wappapello Dam and Reservoir at the foot of the Ozark Highlands to regulate the headwater flow from more than 1,300 square miles of mountain watershed of the St. Francis River; levees on both sides of the river below the dam to the foot of St. Francis Lake and along Little River to the foot of St. Francis Lake; a siphon over the levee at this point to the river channel below; a diversion floodway between the foot of St. Francis Lake and the Poinsett-Cross County line, designated the Oak Donnick Floodway; levees and culverts in the Elk Chute Drainage District, Missouri; and a cutoff on Tyronza River and enlargement of the channel above the cutoff. A total of about 400 miles of levees was authorized by this act.

The first modification of the basic plan was that of the 1941 act which substituted the Cross County Ditch for a portion of the original project below Oak Donnick. Further modification made by the 1950 act provided for improvements in the Little River Basin, enlargement and cleanout of Big Slough and Mayo Ditch, a paved inlet at the head of Cross County Ditch, and improvements in the lower St. Francis River. Provision was also made for relocation of bridges and utilities as required. The improvements authorized in the Little River Basin included extension of the headwater diversion levee, enlargement of floodway ditches, enlargement or construction of major tributary ditches as might be found economically justified, and enlargement or degrading of existing spoil-bank levees as required. The improvements authorized in the lower St. Francis River consisted of improvements on St. Francis Bay and Straight Slough; extension of Oak Donnick Floodway to the vicinity of Marianna, Arkansas, by constructing a levee and a channel, where needed, paralleling the foot of Crowleys Ridge; and protection of the backwater area, including the necessary drainage and pumping facilities, previously covered under the heading "St. Francis River backwater area."

The plan proposed by the Chief of Engineers in House Document No. 308, 88th Congress, 2d session, which formed the legislative basis for the Flood Control Act of 1965, included flood control improvements for which adequate authorization was already available, and proposed some for which additional authorization was required. Included in the latter category were channel improvements for Locust Creek, Big Bay Ditch No. 1, Ditches Nos. 9 and 10 in Poinsett County, Straight Slough Ditch, Varney River, and the Cockle Burr Slough-Buffalo Creek area, all located in the St. Francis River Basin proper, and land acquisitions in the backwater area as mitigation measures for fish and wildlife losses which could otherwise be expected to result from the proposed flood control works. Also authorized were improvements in the Big Lake Fish and Wildlife Refuge area in the Little River Basin, of which approximately half the cost was chargeable to flood control and half to fish and wildlife enhancement. When completed, the project as modified will benefit about 1,250,000 acres in Arkansas and Missouri.

Enlargement, straightening, and restoration of levees in the St. Francis and Little Rivers Basins were begun in 1937 and were followed by channel enlargement, a cutoff of the Tyronza River, and construction of ditches. Construction of Wappapello Dam, also begun in 1938, was finished in 1941. As of 1972, construction had been completed on substantially all of the elements of the basic plan authorized by the 1936 act, except for the channel improvement between Wappapello Dam and Crowleys Ridge. Cross County Ditch, Mayo Ditch, and Big Slough are complete. In the Little River Basin, the Big Lake Floodway Ditch, the Outlet Ditch, Elk Chute Ditch, Ditch No. 81 above Hornersville, the major portion of the headwater diversion levee, and about 21 miles of Ditch No. 66 are complete. In the lower St. Francis River, the floodway channel, St. Francis Bay, Straight Slough, the interior channels, and about 50 miles

of levee are complete. Inevitably, these undertakings included the construction or relocation of highway and railway bridges, together with relocation of utility lines, crossing the floodways and ditches.

A considerable amount of authorized work remains to be constructed in the upper and lower parts of the St. Francis Basin and in the Little River Basin. No construction has been undertaken on the improvements in the Belle Fountain Ditch and Tributaries, Missouri, and Drainage District No. 17, Arkansas, Project, authorized by the 1968 Flood Control Act.

No work has been accomplished on the L'Anguille River Project under the authorization in the 1948 act, which provided for clearing, enlarging, and realigning L'Anguille River below mile 108, and on two of its principal tributaries, Brushy Creek below mile 6 and First Creek below mile 8. The lower 5 miles of the L'Anguille River have been improved as part of the St. Francis Basin Project, and form the realigned main outlet channel of the St. Francis River.

West Kentucky

Under this heading are grouped the contiguous drainage basins of three minor tributaries. Mayfield Creek, most northerly of the three and having a drainage area of 440 square miles, flows northerly and westerly about 62 miles to a confluence with the Mississippi River near Wickliffe. Obion Creek, lying south of Mayfield Creek, and Bayou de Chien, the most southerly, have drainage areas of 321 and 215 square miles, respectively. Both streams flow westerly to join the Mississippi River just above Hickman. Only improvement of Obion Creek was included in the authorization by the 1965 act. The major channel enlargement and realignment from Pryorsburg to the Mississippi River are essential to the effectiveness of part of the authorized upstream watershed protection project of the Soil Conservation Service. The benefits of these projects are inseparable because the upstream project will reduce flow quantities and siltation, and thereby reduce the required channel size and increase the effective life of the downstream project.

Planning of the downstream project is in progress, but no construction has been performed.

West Tennessee

The watersheds of all the major river systems in western Tennessee directly tributary to the Mississippi River are grouped under this heading. The total drainage area of 8,664 square miles is bounded on the north by the watershed divide of the West Kentucky tributary system, on the east by the Tennessee River Basin divide, on the south by the basins of the Tallahatchie River and Nonconnah Creek, and on the west by the Mississippi River. Most northerly is the Obion River with its tributaries spread fan-shaped above the main stem, including North, Middle, South, and Rutherford Forks. Forked Deer River with its tributaries, North, South, and Middle Fork, enters Obion River 3 miles above its mouth. The Reelfoot Lake Basin, extending 35 miles south below Hickman, Kentucky, to the Obion River, is also a tributary of the Obion River. To the south lie, in sequence, the basins of the Hatchie, Loosahatchie, and Wolf Rivers and their tributaries. These streams flow in a generally north and west direction to confluences with the Mississippi River at or above Memphis.

The Alluvial Valley portion of the Obion River watershed is partially protected by the main-stem Mississippi River levees extending from Hickman to near Cates, Tennessee, and from Tiptonville, Tennessee, downstream as far as mile 820 AHP. The Tiptonville-Obion River section of the levee, which was authorized by and constructed under the Flood Control Act of 22 June 1936, was incorporated into the Mississippi River and Tributaries Project by the Flood Control Act of 1946. The 1946 act also authorized the extension of that levee across the Obion River and diversion of the river to empty into

the Mississippi River downstream from the levee extension. Drainage improvements in the Alluvial Valley area were also authorized as a part of the main-stem Mississippi River levee project, including Lake No. 9, Harris Ditch, Running Reelfoot Bayou below the Illinois Central Railroad, and improvements along the Obion River below Lane, main stem of Forked Deer River, and the North Fork of Forked Deer River below Dyersburg. Additional channel improvements for the Obion and Forked Deer Rivers and their principal tributaries were authorized under the 1948 act to provide adequate outlets for lands subject to overflow. Enlargement of the channel of Running Reelfoot Bayou from Reelfoot Lake to the Illinois Central Railroad and modification of the previously authorized channel from the railroad to Obion River were authorized by the 1954 act, which likewise authorized cleanout and enlargement of Bayou de Chien from a point below Hickman to Reelfoot Lake.

Construction of the improvements on the Obion and Forked Deer Rivers was commenced in 1957. About 77 miles of the channel have been completed. The work remaining to be done is on the tributary streams and on the lower 25 miles of the Obion River. Extension of the Tiptonville-Obion levee and construction of the diversion channel have not been started. The improvement of Running Reelfoot Bayou was started in 1956 and completed in 1962. No work has been done on the improvement of Bayou de Chien, Lake No. 9, or Harris Ditch due to a lack of local sponsorship of the required assurances of cooperation.

No work on the Hatchie and Loosahatchie Rivers has been authorized under the Mississippi River and Tributaries Project.

Improvements on Wolf River, authorized by the 1958 act, included channel realignment and enlargement from mile 38 to mile 3.5, diversion of Wolf River from this point westward into Loosahatchie Chute, enlargement of the chute to the Mississippi River, a roadway levee closure across the former channel at the head of the diversion, and realignment and clearing of the lower 3 miles of tributary Fletcher Creek. The work was begun in 1960 and was substantially completed in 1964.

Lower White and Cache Basins, Arkansas

The lower 169 miles of White River and its tributary area below Peach Orchard Bluff, near Georgetown, Arkansas, are within the jurisdiction of the Mississippi River Commission. Amendments of the basic Mississippi River and Tributaries Flood Control Act by the 1946, 1950, 1958, and 1965 acts authorized improvements within this area, including local flood protection projects at Des Arc, DeValls Bluff, Clarendon, and Georgetown, Arkansas; a levee on the east bank of White River between Augusta and the mouth of Cache River at Clarendon; and flood control and drainage improvement projects on Cache River and its principal tributary, Bayou DeView, and on Big Creek and its tributaries. Also included were a levee, drainage outlet structures, and a pumping station to serve the White River backwater area, all of which have been previously described.

Of the total area of 27,765 square miles drained by the White River, about 7,000 square miles are in the Mississippi River Alluvial Valley. The main-stem project levee of the Mississippi River extending south from Helena, together with the White River backwater levee, protects a substantial part of the lower White River Basin from floods. Bayou Des Arc, a right-bank tributary, has a drainage area of 682 square miles. The left-bank tributary, Cache River, together with its tributary, Bayou DeView, has a drainage area of 2,705 square miles, and Big Creek, also a left-bank tributary, has a drainage area of 1,060 square miles.

Construction of the Augusta to Clarendon levee was begun in 1946, and by 1954, 39.5 miles of the total length of 49.2 miles were complete to approved grade and section. Construction of the

uncompleted portion is not desired by local interests. The authorization included flood protection for the small communities of Georgetown and DeValls Bluff. No work has been done at Georgetown. The DeValls Bluff protection included a 500-foot levee, a gated culvert, and a pumping plant, construction of which was completed in 1952. The protection authorized for the town of Des Arc consisted of a 7,700-foot levee, floodgates, and a pumping station for both storm drainage and sewage. This feature was completed in 1954. The Clarendon local levee, about 6 miles long, which local interests completed in 1937, was authorized by the 1965 act to be enlarged, with extension of drainage culverts and replacement of gates. Preconstruction planning is in progress. Preconstruction planning is also in progress on the authorized 231 miles of channel improvements on Cache River (including the minor extensions above Hickoria, authorized by the 1965 act) and on Bayou DeView. Advance engineering and design are in progress on the Big Creek feature which includes straightening, enlarging, and cleaning out 84 miles of Big Creek channel and 108 miles of the 10 major laterals, and construction of 16 low dams to minimize fish and wildlife losses.

Improvement of the White River by the Corps of Engineers for navigation began in 1871. The existing authorization, not under the Mississippi River and Tributaries Project, is for channel maintenance between the mouth and the effective head of navigation at Batesville, Arkansas, by snagging and dredging operations and by contraction works. Due to a decline in traffic, channel maintenance was discontinued in 1951, but recent traffic increases necessitated a resumption of maintenance below Augusta, beginning in Fiscal Year 1962. Improvement of the White River channel from the mouth to mile 10 will be constructed and maintained as part of the Arkansas River Navigation Project. The existing White River Project was modified in 1968 under authority of section 107 of the 1960 River and Harbor Act to provide a 125-foot-wide channel, with minimum depth of 5 feet and a depth of 8 feet at a stage of 12 feet on the Clarendon gage, from the mouth to Augusta. However, this modification has not been funded for construction.

Lower Arkansas River

The Arkansas River, which drains an area of about 160,500 square miles, joins the Mississippi River about 20 miles above Arkansas City. The 1928 act included the 100-mile reach below Pine Bluff, Arkansas, within the Alluvial Valley flood control project. In 1961, in connection with commencement of the navigation features of the Arkansas River Basin Comprehensive Plan, responsibility for locks and dams and for bank stabilization above mile 37 was assigned to the U. S. Army Engineer Division, Southwestern. Remaining under the jurisdiction of the Mississippi River Commission are the north- and south-bank levees and bank stabilization for flood control purposes below mile 37.

The south-bank levee, a part of the main line of protection for the Boeuf-Tensas Basin as discussed subsequently begins at Pine Bluff and extends 85.4 miles along the Arkansas River to a junction with the Mississippi River west-bank levee. The engineering plan of the 1928 act provided, "To protect floodwaters from entering the Tensas Basin, except into the floodway during high floods, the levees on the south side of the Arkansas will be strengthened and raised about 3 feet as far upstream as necessary." The prescribed modifications were not completed until 1941. Revision of the levee grade in 1942 necessitated further work which was finished in 1961. Construction of a drainage structure for Harding Drain in Pine Bluff through the south-bank levee was substantially completed in 1967. Only 25 percent of the cost of this feature was charged to Mississippi River and Tributaries funds, and 75 percent was charged to Arkansas River and Tributaries funds.

The north-bank levee extends 61.5 miles from Tucker, north of Pine Bluff, to the vicinity of Gillett

of which the upper 56.2 miles have been completed and the lower 5.3 miles have been deferred. It is a segment of the North Little Rock to Gillett levee, originally constructed by local interests on substantially the same alignment, which was adopted by the Flood Control Act of 22 June 1936 to protect agricultural lands and communities. That portion along and below Plum Bayou was made a part of the Mississippi River and Tributaries Project by the 1946 act. When completed, this levee will protect an area of about 720 square miles. The two large floodgates at Little Bayou Meto and Big Bayou Meto and 27 lesser drainage structures through the north-bank levee were included in the construction by local interests prior to 1936. Enlargement of the levee from a point opposite Pine Bluff to a point south of Gillett was essentially completed in 1959, and a new levee extension to Tucker was completed in 1960. No work has been done on the authorized 5.3-mile extension to Gillett. Other uncompleted work includes replacement of the Little Bayou Meto floodgate, modification of the Big Bayou Meto floodgate, construction of seepage and stability berms, and construction of roads on levees.

At the time of transfer of responsibility for bank stabilization above mile 40, approximately 31.9 miles of operative bank protection works were in place on both sides of the Arkansas River between Pine Bluff and the mouth. Of this figure, 11.2 miles were constructed as a part of the Mississippi River and Tributaries Project, and 20.7 miles, to afford emergency bank stabilization and channel rectification under the authority for the multipurpose development of the Arkansas River and tributaries. By 1972, 5.5 miles of operative pile and stone dikes were in place on the reach below mile 40.

Grand Prairie Region and Bayou Meto Basin

This project area of 2,240 square miles lies in east-central Arkansas below the latitude of DeValls Bluff between the basin of the lower Arkansas River on the southwest and the basin of the lower White River on the northeast. It includes the drainage basin of Bayou Meto, tributary to the Arkansas River, and the adjoining lands known locally as the Grand Prairie, which are partly tributary to White River on the east and to the Arkansas River on the west. The Bayou Meto Basin is subject to flood and drainage problems similar to those of other tributary basins in the Alluvial Valley. The Grand Prairie area is well above the flood plains of neighboring streams and so is not subject to flooding by those streams. The 1950 act included authorization of channel improvements for flood control on Bayou Meto and on Little Bayou Meto and its tributaries, and for a pumping plant and system of ditches in the Grand Prairie area to import water from the White River for rice irrigation to supplement the supply obtained by pumping of ground water. The authorization called for local cooperation, consisting of the provision of lands required for construction of the project, maintenance and operation of the completed works, and reimbursement of the United States for the portion of the cost allocated to local interests for providing and delivering water for agricultural purposes to the Grand Prairie area which is over and above other requirements of local cooperation.

The two project features were restudied during the comprehensive review of the Mississippi River and Tributaries Project in 1959. No modification of the Grand Prairie feature was recommended. Study of the Bayou Meto feature developed that the 1950 plan contemplated channels that would be inadequate for the current requirements of the area, and that additional improvement of Indian Bayou was needed. As both changes could be effected under the 1950 authorization, no additional authorization was required.

No work has been done on the Grand Prairie feature because of the inability or unwillingness of local interests to organize and meet the requirements of local cooperation. In the lower Bayou Meto Basin, inability of local interests to resolve disagreements concerning the relative importance of drainage improvements and the preservation of fish and wildlife values has likewise held up this feature.

Yazoo River Basin

The basin of the Yazoo River lies in northern Mississippi, extending from the Mississippi-Tennessee State line southward to the latitude of Vicksburg. It occupies an area of 13,400 square miles, of which 6,600 square miles are in the Alluvial Valley of the Mississippi River, and the remaining 6,800 square miles are rolling to rugged hill lands. The responsibility of the Corps of Engineers in the Yazoo Basin is comprised of three components—the Yazoo headwater area, the Yazoo backwater area, and the Big Sunflower area, for each of which there is separate authorization by specific legislation. The adopted overall plan of improvement includes protection against headwater floods of streams in the basin, protection against backwater floods of the Mississippi, and major drainage in the delta area.

The Yazoo headwater area is that portion of the drainage area above Yazoo City, comprising about 2,300 square miles in the Alluvial Valley and 6,600 square miles of hill lands. The Yazoo backwater area, in west-central Mississippi between the east-bank Mississippi River levee and the hills, is discussed previously under the heading, "Backwater Areas." The Big Sunflower area comprises about 4,100 square miles in the northwest portion of Mississippi bordering on the Mississippi River east-bank levee. The two major outlets are Big Sunflower River with a drainage area of 3,100 square miles, and Steele Bayou with a drainage area of 750 square miles. The watersheds of Deer Creek and Little Sunflower River are connected by Rolling Fork Creek. Little Sunflower River is a distributary of Big Sunflower River.

Prior to initiation of construction in the Yazoo headwater area, the capacities of stream channels in the area were insufficient to carry local runoff, and consequently adjacent areas were overflowed. Rapid runoff from hill areas increased the flooding which occurred almost annually, much of it during the crop-growing season. The duration of flooding ranged from as little as 3 days in the upper portion of the basin to as much as 5 months in the lower basin. The basic legislation for this feature, the Flood Control Act of 15 June 1936, authorized the Chief of Engineers to construct seven detention reservoirs on the hill streams, and at the same time gave him broad discretionary authority as to location of the reservoirs and also authority to "* * * substitute levees, floodways, or auxiliary channels, or any or all of them, for any or all of the seven detention reservoirs * * * for control of floods of the Yazoo River * * *." Subsequent acts relieved local interests of participation in the project, removed cost limitations, and provided flexibility in use of authorized appropriations. Other legislative provisions extended the project to include drainage of runoff from the watershed of McKinney Bayou or provision of increased pumping capacity; to include improvements in the area between the Yazoo-Tallahatchie-Coldwater River system and the hills to protect against overflows from the main stem and the hill tributaries; and to include channel improvements in Alligator and Catfish Bayous, Bear Creek, and Whiteoak Bayou. Acquisition in fee of lands in the Hillside Floodway and installation of water control structures in Old Techeva Creek and McIntyre Lake were authorized by the 1965 act for mitigation of fish and wildlife losses. Construction of five water control structures in the Will M. Whittington Auxiliary Channel for the specific benefit of fish and wildlife was also included in that authorization.

Under the basic legislation cited, four detention reservoirs have been constructed on the headwaters (see "Reservoirs" hereinafter), and construction of an extensive system of levees, channel improvements, and local protection is underway for flood control and major drainage on the interior stream basins.

Planning for the first construction on the Yazoo headwater project began in 1935 with studies pertaining to Sardis Dam and Reservoir. Channel improvement on the main stem and certain tributaries of the Yazoo-Tallahatchie-Coldwater Rivers started in 1939 with channel enlargement operations on the Yalobusha. Construction of cutoffs, channel enlargement, and channel clearing were commenced in the

ensuing 5 years on the Yazoo, Tallahatchie, Little Tallahatchie, and Coldwater Rivers and on the Panola-Quitman Floodway and Cassidy and Bobo Bayous. A new channel for Arkabutla Canal was constructed in 1948. Clearing of Yocona River was started in 1952. The Lower Auxiliary Channel (later named the Will M. Whittington Auxiliary Channel) was started in 1956 with construction of the lower 7 miles, and was completed in 1962. Clearing, snagging, and channel excavation were initiated in 1957 on David and Burrell Bayous, and in 1964 on Tchula Lake and the Hillside Floodway. Channel construction on several tributary streams has not been initiated, nor has construction of the Upper Auxiliary Channel been started. As of 1972, 564.3 miles of channel improvement, of a planned total mileage of 851.2 miles in the headwater area, have been completed.

The extent of levee requirements for the project could not be determined until the capacities of the headwater reservoirs had been fixed. Studies reported upon in House Document 198, 73d Congress, 2d session, showed that sufficient reservoir capacity was not available to permit the entire hill runoff to be withheld during flood periods and released later at such a rate that no overflow would occur. In 1942, it was estimated that local interests had constructed 370 miles of levees. This figure included 270 miles by levee and drainage districts, 70 miles of private levees, 8 miles of intermittent sandbag levees, and 22 miles of roads used as levees. Studies begun in 1942 concerned extension and enlargement of this discontinuous protection, construction of new levees, and construction of floodgates and pumping plants. By 1943, 3 miles of levee had been built to approved grade and section. By 1944, the total was 33 miles, but for the next 12 years, construction proceeded so slowly that a total of only 49 miles had been completed by 1956. Thereafter, the construction rate accelerated and to date, 258.8 miles have been completed in the headwater area, of a total of 574.6 miles planned to be constructed. The figure included 27.2 miles of local protection works, 61.3 miles along the auxiliary channel (Will M. Whittington Auxiliary Channel), 148.3 miles along the main stem, and 22.0 miles on tributaries. Protection works for Yazoo City and Belzoni have been completed and the Greenwood protection works are 64 percent complete. Pumping facilities and channel improvement for McKinney Bayou were begun in 1960 and completed in 1962. Lands in the Hillside Floodway area have been acquired for fish and wildlife mitigation, but no work has been accomplished on the other mitigation features or on the control structures for fish and wildlife enhancement.

The project for flood control on the Big Sunflower, Little Sunflower, Hushpuckena, and Quiver Rivers and their tributaries, and on Hull Brake-Mill Creek Canal, Bogue Phalia, Ditchlow Bayou, Deer Creek, and Steele Bayou, Mississippi, provides for major drainage outlets totaling about 740 miles in length consisting of channel clearing, channel enlargement and realignment, channel cutoffs, and construction of weirs for control of low water levels for maintenance purposes. Although the project was authorized by the 1944 act, work on it was not commenced until after its incorporation into the Mississippi River and Tributaries Project by the 1946 act, which authorized extension of the improvement upstream and downstream, including cutoffs, as necessary, to effectuate the purposes of the plan. The 1962 act added construction of channel improvements in Gin and Muddy Bayous, and the 1965 act provided for additional channel work on Steele Bayou and certain of its tributaries and authorized water control structures for fish and wildlife enhancement. Additional improvements in the Steele Bayou Basin were authorized by resolutions of the Public Works Committee of the House and Senate in December 1970 under section 201 of the 1965 Flood Control Act. The 1950 act reduced the local cooperation stipulated in the original legislation to that of section 3 of the 1928 act, which defined maintenance as normally including "* * * such matters as cutting grass, removal of weeds, local drainage, and minor

repairs of main river levees * * *." However, the authorization by the 1965 Flood Control Act of the water control structures for fish and wildlife enhancement was conditioned on an equal division of costs between the Federal Government and local interests and, in addition, holding and saving the United States free from damages due to the construction works, and operating and maintaining the works after completion.

The initial construction contracts in 1947 involved Big Sunflower River, Quiver River, Deer Creek, and Steele Bayou. Within 3 years, a total of 77.5 miles of channel improvement had been completed. Except for fiscal years 1953, 1955, and 1971 when no construction was in progress, channel improvement operations on the several streams and their tributaries have continued. To date, 636 miles of channel improvement have been completed. The conclusion from studies of projected conditions and of agricultural developments expected to occur after completion of the initial improvement project on Steele Bayou and its tributaries was that greater channel capacity should be provided to reduce the frequency of flooding during the crop-growing season. Substantial progress has been made on the additional work authorized by the 1965 act. No work has been done on the water control structures for enhancement of fish and wildlife or on the recently authorized additions in the upper basin.

Boeuf and Tensas Rivers and Bayou Macon, Arkansas and Louisiana

The watersheds of the Boeuf and Tensas Rivers and Bayou Macon are contiguous and include the part of the Alluvial Valley of the Mississippi River lying west of that river and east of the Ouachita River and its tributary, Bayou Bartholomew, between Pine Bluff, Arkansas, and Jonesville, Louisiana. The basins have an overall length of about 190 miles in a generally north and south direction and an average width of about 30 miles. Of the area's 5,300 square miles, about 1,350 square miles are in Arkansas and 3,950 square miles are in Louisiana. The basins are protected from Mississippi and Arkansas River floods by the south-bank Arkansas River levee and the connecting west-bank main-line Mississippi River levee, which extend from the high ground at Pine Bluff, Arkansas, to Old River, Louisiana, a distance of about 373 miles. Protection from Ouachita River floods is furnished by the east-bank Ouachita River levee which extends from high ground near Bastrop, Louisiana, to the vicinity of Sandy Bayou, near the mouth of Boeuf River, a distance of about 112 miles. About 880 square miles in the lower end of the basins are subject to flooding by backwater from the Mississippi, Red, and Ouachita Rivers. Interior drainage within the basins is carried through a complex system of interconnected waterways which empty into the Ouachita River through the Boeuf and Tensas Rivers. Drainage in the basins under natural conditions was poor due to inadequate channel capacities and flat slopes. Extensive drainage improvements constructed by local interests in the Arkansas portion of the basin in the early 1920's caused substantial increases in both stages and discharges in the portion of the stream channels in Louisiana. Drainage divides within the basins are poorly defined because of the relatively flat terrain and the multiplicity of interconnecting channels. Hence, wide variations in stages, areas overflowed, and discharges for large floods may occur in individual streams from storms that have essentially the same apparent intensity.

The initial project for the Boeuf and Tensas Rivers and Bayou Macon was authorized by the Flood Control Act of 1944 as a Flood Control, General project. It provided for improvements for flood control on Boeuf River from the Arkansas-Louisiana State line to the head of Bayou Lafourche, and its tributary, Big and Colewa Creek; on Tensas River; and on Bayou Macon, from mile 158 to its mouth. The improvements included clearing and snagging, channel enlargement, and channel realignment. The 1946 act incorporated the project into the Mississippi River and Tributaries Project and extended the authorized

work to include improvement of Bayou Lafourche, including cutoffs, as the main drainage outlet of the basin, and the improvement of the Boeuf and Tensas Rivers and Bayou Macon north of the Louisiana State line, including cutoffs. The 1950 act relieved local interests of the previously prescribed responsibility for cooperation except for that of maintenance in accordance with section 3 of the Flood Control Act of 1928. The 1958 act further extended the authorized work to include improvement of portions of Canals 18 and 19, Black Pond Slough, Kirsch Lake Canal, Fleschmans Bayou, Caney Bayou, and Rush Bayou, subject to the proviso that construction should not be commenced on any of these minor modifications until the previously authorized Boeuf and Tensas Rivers and Bayou Macon improvements had been completed. The 1965 act added channel improvements in Mill and Vidal Bayous, provided that local interests would maintain the work after completion. Studies on which the 1965 act was based concluded that drainage development would require enlargement of main channels then under construction; that enlargement in Tensas River and Bayou Lafourche eventually would be required; that enlargement in Big and Colewa Creek and in Boeuf River was warranted for early construction; and that this added work could be accomplished under available authority. Finally, the 1968 act further modified the project to include a pumping plant with gravity drainage structure in the vicinity of Macon Lake, Arkansas, together with related facilities, to divert flows to the Mississippi River that would otherwise enter Lake Chicot. The required local cooperation includes the administration of all recreation facilities constructed as a part of the project, provision of all lands involved in specific recreation facilities, contribution of a lump sum based on the first costs of specific recreation facilities, operation and maintenance of the recreation facilities, and operation of the gates in the dams in Connerly and Ditch Bayous in accordance with an agreed plan, including ordinary maintenance of these structures.

Field investigations and preparation of plans and specifications were started in Fiscal Year 1946 with Flood Control, General funds. Construction of channel improvements in Tensas River and Big and Colewa Creek was started in Fiscal Year 1947. The operations were broadened the following year to include Bayou Lafourche. By the end of Fiscal Year 1953, there had been completed 89 miles of channel improvement in Big and Colewa Creek, 85 miles in Tensas River, and 34 miles in Bayou Lafourche. Also completed or under construction or reconstruction were numerous local, State, or Federal highway bridges and alteration or relocation of utility lines. Channel enlargement and realignment of the Boeuf River were begun in 1954, and work on Big Bayou, Bayou Macon, and the remaining minor tributaries and canals followed within several years. To date, channel improvement has been accomplished on about 711 miles of project streams. No work has been done on Mill Bayou, Bayou Vidal, Kirsch Lake Canal, or on the pumping plant in the vicinity of Macon Lake.

Lower Red River

The engineering plan adopted by the Flood Control Act of 1928 provided for strengthening and raising the levee on the south bank of the Red River sufficiently to keep floodwaters from entering the Atchafalaya Basin except in the floodway. As with the Arkansas River south-bank levee, it was contemplated that the Red River levee would be raised 3 feet as far upstream as necessary. Carrying out this plan resulted in a levee 60 miles in length, extending from high ground near Hotwells to high ground near Moncla. Together with the Mansura Hills to Hamburg levee and the west Atchafalaya Basin protection levee, it protects the area west of the floodway from backwaters of the Mississippi and Red Rivers. The 1965 act included authorization of minor enlargements along 15 miles of levee between Hotwells and Alexandria in order to provide the authorized 4-foot freeboard over the revised 1956 flow line. Below Alexandria, the existing levee provides freeboard in excess of the authorized 3 feet over

the revised flow line; hence, no change in grade below Alexandria was proposed. The work of strengthening and raising the levee was in progress soon after passage of the 1928 act, and continued in varying amounts almost every year until 1951. In succeeding years, the levee construction has consisted of correction of minor deficiencies. As of 1970, 48.5 miles of levee have been completed to grade, and about 8.2 miles are not yet to full cross section.

In addition, about 7.6 miles of bank protection have been constructed since 1947. These works are at 13 locations on the south bank between Boyce and Moncla, and were required to avoid the necessity of setting back the levee. They include standard revetment of board mattress with riprap or concrete upper bank pavement, pile dikes, and one experimental installation of steel permeable triangular frame dikes.

Bayou Cocodrie and tributaries

The watershed of Bayou Cocodrie and tributaries lies generally south and west of the city of Alexandria, Louisiana. The total drainage area of 965 square miles is naturally divided into two distinct territories by a well-defined escarpment, westward of which the land is considerably higher than to the east. In the higher area, streams are confined in valleys with steep sides, and the configuration of the terrain is conducive to relatively high rates of runoff. Eastward of the escarpment, the general characteristics of the land are those of an alluvial plain. Surface slopes are very flat and the watercourses assume the characteristics of alluvial streams. Bayou Rapides has its source near Hotwells, about 15 miles west of Alexandria, and meanders generally in an easterly direction, emptying into the Red River immediately north of Alexandria. Prior to Federal improvement, the discharge during periods of medium to low stages in the Red River was by gravity through a floodgate constructed and operated by local interests. When the Red River was at or near flood stage, the floodgate was closed and the Bayou Rapides flow was only partially cared for by a pumping plant. Bayou Boeuf has its source near McNutt, Louisiana, at the foot of the hills about 10 miles west of Alexandria, and flows generally in a southeasterly direction approximately 112 miles to its confluence with Bayou Cocodrie near Washington, Louisiana. At about mile 90, it receives the flow from Bayou Robert, which has its source within the city of Alexandria. About 2 miles downstream from the junction of Bayou Robert with Bayou Boeuf, a portion of the flow of Bayou Boeuf is diverted eastward through Bayou Lamourie to the Chatlin Lake Canal drainage system. Bayou Cocodrie has its origin at the confluence of Little Bayou Cocodrie and Spring Creek in the hills in the vicinity of Clear Water, Louisiana, then meanders southeastward about 45 miles to its junction with Bayous Boeuf and Courtableau.

In the Bayou Rapides Basin, flood stages in Red River made it necessary to keep the floodgate at Alexandria closed during most of each year, and during such periods the discharge of Bayou Rapides exceeded the capacity of the pumping plant whenever rainfall over the Bayou Rapides Basin was only slightly above normal. In the Bayou Boeuf Basin above Bayou Lamourie, flooding resulted because of inadequate capacity of the principal drainage channels. Because of the flat terrain, the numerous small streams were sluggish and tortuous, and with the added disadvantage of inadequate arterial drainage, were ineffective for drainage purposes. Below Bayou Lamourie, the problem in Bayou Boeuf was simply inadequacy of mainstream channel capacities. In the affected portions of the Bayou Cocodrie Basin, the problem was similar to that in the upper Bayou Boeuf Basin. The capacity of the channel in Bayou Cocodrie below Clear Water was inadequate to carry runoff from major storms without overtopping its banks for a considerable part of its length. Drainage conditions of lands lying between Bayou Cocodrie and Bayou Boeuf were similar to those in the upper Bayou Boeuf Basin. Bayou Courtableau, formed

at the confluence of Bayous Boeuf and Cocodrie, at one time flowed in a southeasterly direction and emptied into the Atchafalaya River. At that time, backwater stages in Bayou Courtableau, resulting from flood stages in the Atchafalaya River, retarded the outflow from the Boeuf and Cocodrie channels. As the levee along the west bank of the Atchafalaya was progressively extended southward, Bayou Courtableau was finally closed; but prior to that time, its lower reaches had been completely shoaled by silt from the Atchafalaya River, and the Bayou had broken through its south bank in numerous places and discharged its floodwaters into the adjacent swamps of the Atchafalaya Basin. Construction of the Atchafalaya Basin floodways pursuant to the Flood Control Act of 1928 resulted in damming of Bayou Courtableau by the west-basin protection levee. Final closure was made in 1935, when the first lift of the levee was completed for some 40 miles below Bayou Courtableau. The large landside borrow pits excavated in building the levee formed a continuous drainage channel extending into Lake Fausse Pointe, thence into Grand Lake. Flow from Bayou Courtableau into this drainage channel was effected by means of a wide, shallow spillway cut through the high south bank of the Bayou at such an elevation as to cause the low water flow of Bayou Courtableau to follow Bayou Teche, but such that the major portion of the floodflows of Courtableau would flow by way of the borrow pit channel.

The improvements for the feature Bayou Rapides, Boeuf, and Cocodrie, Louisiana, authorized for construction by the 1941 act, included a control structure in the south bank of Bayou Rapides to control the diversion of flow from Bayou Rapides into the Boeuf Basin; a diversion channel from the south bank of Bayou Rapides near Alexandria to Bayou Boeuf at the mouth of Bayou Clear; clearing and excavation of Bayou Boeuf channel from the Rapides-Boeuf diversion channel to the mouth of Valentine Creek; Bayou Lamourie control structure for regulating both high water and low water flow in Bayou Lamourie; control structures in the right bank of Bayou Boeuf at the head of the Boeuf-Cocodrie diversion channel to divert certain flow to Bayou Cocodrie by way of the diversion channel; the Boeuf-Cocodrie diversion channel from Bayou Boeuf near Union Chapel to Bayou Cocodrie below St. Landry; channel enlargement and rectification of Bayou Cocodrie from the head of Bayou Courtableau to the mouth of the diversion channel; and minor highway and railroad bridges.

Planning for construction was underway by 1943, but construction did not begin until 1947. Initial operations included excavation in the lower reaches of Bayou Cocodrie and of the Boeuf-Cocodrie diversion channel, and construction of the Bayou Rapides control structure. This structure was completed in 1949, and the Lecompte and Lamourie structures were completed in 1950 and 1952, respectively. By 1952, there had also been completed an improved and continuous diversion channel from mile 0.0 to the Bayou Rapides drainage structure, a distance of 59.8 miles, and the enlargement of 3.6 miles of Bayou Boeuf between the diversion channel and Bayou Lamourie. Numerous highway, railroad, and foot bridges had also been constructed or reconstructed. As of 1972, work required to complete the project includes enlargement of 13.5 miles of upper Bayou Boeuf and channel improvement of 25.3 miles of Bayou Cocodrie which cannot be undertaken until additional outlet capacity is provided by construction of the 13.7-mile-long Washington to Courtableau diversion channel and the conjoined enlargement of the Bayou Courtableau drainage structure. The latter two items are modifications added by the Comprehensive Review Report of the Mississippi River and Tributaries Project of 1959 as warranted and necessary, and which can be accomplished under available authority. These works can be undertaken after local interests have fulfilled the requirements of local cooperation.

Teche-Vermilion Basins

The Bayou Teche and Vermilion River Basins are located in south-central Louisiana, adjacent to

and west of the Atchafalaya Basin Floodway. The entire basins are made up of coastal marsh, recent flood plains of the Mississippi and Red Rivers, and prairies. The higher or prairie lands are especially suited to rice cultivation. Irrigation of the ricelands started about 1885, and the water requirements have increased steadily as rice irrigation has become one of the principal activities in the basins. Originally, the Atchafalaya River was the major source of the irrigation water which flowed to Bayou Teche and the Vermilion River through Bayou Courtableau.

Construction of the west Atchafalaya River levee and the west Atchafalaya Basin protection levee blocked the connection between Bayou Courtableau and the Atchafalaya River, thereby precluding any diversion from the Atchafalaya River to the Teche-Vermilion Basins and considerably decreasing the fresh-water supply available in these streams for irrigation and other purposes. Therefore, the Bayou Darbonne drainage structure was built in 1942 to provide an opening through the west protection levee, and restore the former diversions. Subsequently, the water supply diversion from backwater that entered the floodway around the end of the Atchafalaya River levee was about the same as that which occurred prior to construction of the basin protection levee. In 1948, the west Atchafalaya River levee was extended about 10 miles downstream to the vicinity of Butte La Rose in order to reduce backwater stages in the west Atchafalaya Floodway by an estimated 6 feet. This reduction afforded flood control benefits to large areas in the west Atchafalaya Floodway system from Krotz Springs and, in addition, permitted construction to be expedited on the high-level railroad and highway crossing of the floodway between Krotz Springs and Courtableau.

However, the lowering of backwater stages in the floodway seriously reduced diversion through the Bayou Darbonne drainage structure. The Bayou Courtableau drainage structure and outflow channel were built in 1956 to pass floodflows from the landside borrow pit into the west Atchafalaya Basin Floodway. Although these facilities can be used to pass water from the floodway into Bayou Courtableau and then into Bayou Teche and the Vermilion River, stages are seldom high enough in the floodway to permit diversion to the streams to the west. It is estimated that the Atchafalaya Floodway feature of the Mississippi River and Tributaries Project prevents inflows up to 500 c.f.s. to an area that needs the inflows for municipal and industrial water supply, irrigation, and pollution abatement. In addition, an analysis in 1963 by the U. S. Public Health Service of existing and future water supply needs in the Teche-Vermilion area, showed that a serious water shortage existed, and that the deficiency would increase with the projected growth of population and industrial and agricultural production.

Further studies showed that the deficiencies could be corrected by providing an additional water supply in Bayou Courtableau at the head of Bayou Teche, and that the best source of supply was the Atchafalaya River. In order to assure efficient utilization of this water in the Teche and Vermilion Basins, it is necessary to provide a means of lifting the water from the Atchafalaya River and conveying it to Bayou Courtableau for distribution through existing channels. Control structures are required in Bayou Fusilier and the Loreauville Canal, and between Bayou Courtableau and the levee borrow pit, to regulate the flow in the various streams to needs at particular times. The plan of improvement authorized by the 1966 act includes a pumping station on the Atchafalaya River, upstream of Krotz Springs, with a capacity of 1,050 c.f.s.; a low-leveed channel to convey the pumped water to Bayou Courtableau, with an inverted siphon to convey the flow under Big Darbonne Bayou and a gated control structure in the west Atchafalaya Basin protection levee; a gated culvert between Bayou Courtableau and the lower borrow pit channel; a slotted weir in Bayou Fusilier to limit flows between Bayou Teche and the Vermilion River; and a sector-gated control structure in the Loreauville Canal for passage of navigation and for controlling flows between Bayou Teche and the borrow pit channel.

A division of costs was developed that limited the Federal Government's participation to the initial construction cost, whereas the local interests' participation included provision of lands, maintenance and operation of facilities, and provisions for replacements and future expansions. The authorization includes the stipulation that local interests agree to enlarge the pumping plant to bring the total capacity to not less than 1,300 c.f.s., which is that necessary to insure delivery of 1,000 c.f.s. to the upper Teche at Port Barre. The need for supplemental surface water for the month requiring maximum flow in the basin is estimated to be 1,000 c.f.s. by the year 2020.

As of 1972, preconstruction planning is underway, but no construction has been performed.

Mississippi-Atchafalaya area

The Mississippi-Atchafalaya area lies in southeastern Louisiana and extends from the latitude of Morganza southward to the Gulf of Mexico. The lower Morganza Floodway guide levee and the east Atchafalaya Basin protection levee form a continuous line of protection from the Morganza control structure to the mouth of the Atchafalaya River below Morgan City. Together with the west-bank levee of the Mississippi River between Morganza and Donaldsonville, it protects an area of 1,719 square miles tributary to Bayou Boeuf from overflow by the Mississippi River and the Atchafalaya Floodway. An additional area of 2,406 square miles, drained by Bayous Lafourche and Terrebonne and a chain of lakes tributary to Barataria Bay, is protected from Mississippi River overflow by the west-bank Mississippi River levee extending from Donaldsonville to Venice. The area is drained southward through the levee borrow pits, Bayou Lafourche, and streams tributary to Barataria Bay. There are many improved navigation channels in the area, and the State of Louisiana and local interests have improved a considerable length of tributary drainage. The only Federal project for flood control and drainage in this area, other than the main-line levee system, is that for channel improvement in Bayou Chevreuil between Donaldsonville and Lac des Allemands. This is not a part of the Mississippi River and Tributaries Project and is inactive.

Two of the four salinity control structures for fish and wildlife enhancement, authorized by the 1965 act, are located in the Mississippi-Atchafalaya area. The sites are near Myrtle Grove and near Homeplace in the west-bank Mississippi River levee. The purpose of each structure is to permit the introduction of fresh water into the coastal marsh area to reduce the salinity in oyster-producing areas. No preconstruction planning has been begun.

Pontchartrain Basin area

The Pontchartrain Basin area lies in southeastern Louisiana and southwestern Mississippi between the Mississippi and Pearl Rivers. The principal streams are the Amite and Tickfaw Rivers, which empty into Lake Maurepas, and the Tangipahoa and Chefuncte Rivers, which empty into Lake Pontchartrain. The area is protected from Mississippi River floods by the left-bank levee extending from Baton Rouge to New Orleans, continuous except for the Bonnet Carré spillway. The levee continues below New Orleans to mile 11.5 above the Head of Passes. A State of Louisiana project—the Pointe a la Hache Relief Outlet—consists of a gap in the levee between miles 44 and 33 to allow the discharge of floodwaters at high stages directly into Breton Sound.

Features of the Mississippi River and Tributaries Project within the Pontchartrain Basin area are the Lake Pontchartrain levees in Jefferson Parish, the Amite River bank protection, the Baton Rouge Harbor (see "Navigation" hereinafter), and two salinity control structures.

The Lake Pontchartrain levee feature was authorized by the 1946 act as a Flood Control, General project. By the 1950 act, it was incorporated into the Mississippi River and Tributaries Project and

enlarged in scope to provide increased protection against storm-developed tides and wind-driven waves normal to the area. As modified, it included construction of 10.2 miles of protection levee along the lakefront in Jefferson Parish, and enlargement of 7.2 miles of levee along the St. Charles and Orleans Parish lines to connect the lakeshore levee to high ground. The works protect about 40 square miles of potential residential area from storm tides in Lake Pontchartrain. Because of basic policy aspects involving this feature, covering the extent of Federal responsibility for protection of areas from lake floods and the major benefits expected from land enhancement, the terms of local cooperation included the requirement that local interests contribute 25 percent of the cost of the construction works. Local interests were also required to rehabilitate and improve the interior drainage facilities.

Construction of the lakefront and return levee enlargements and the wave-wash protection was begun under the Mississippi River and Tributaries Project in 1950 and was completed in 1965. By the Flood Control Act of 1965, the barrier project for hurricane flood protection on Lake Pontchartrain was adopted under Flood Control, General. One feature of this plan includes the incorporation of the existing Jefferson Parish levee into a continuous south-shore levee to extend from Bonnet Carré spillway to South Point. The only modification of the existing levee under the Mississippi River and Tributaries Project was to extend its riprap slope protection upward to elevation 8.0 feet, mean sea level.

The Amite River improvement, authorized by the 1950 act, provides for bank protection works to arrest a serious bank-caving condition at the historic Amite River Baptist Cemetery at mile 63. Local interests have completed alternative work for the necessary protection, and the Federal project is inactive. A Flood Control, General project for channel improvement for flood control in Amite River and tributaries from near Baton Rouge to the mouth was completed in 1964.

The salinity control structures to be constructed in the Pontchartrain Basin area are two of the four authorized by the 1965 act. They are to be located in the east-bank levee near Scarsdale and Bohemia. Preconstruction planning of the Bohemia structure was begun in Fiscal Year 1969.

Reservoirs

The report of the Chief of Engineers, dated 1 December 1927, on flood control of the Mississippi River in its Alluvial Valley (House Document 90, 70th Congress, 1st session) includes the description of a study made of a comprehensive system of reservoir control in the Mississippi watershed. The conclusions of the report were that reservoir capacity sufficient to reduce flows to the capacity of the leveed channels then existing would cost several times as much as the complete project being recommended. In finding that reservoirs were not a feasible method of flood control on the main stem, the report confirmed earlier conclusions that, to be of maximum value, flood control reservoirs must be located relatively close to the areas they are to protect. However, the opinion was expressed that many reservoirs on the tributaries which would be of little help on the Mississippi would be of great value in the control of floods on the tributaries.

Section 10 of the 1928 Flood Control Act provided that projects for flood control on all tributary streams of the Mississippi River system subject to destructive floods should be prepared and submitted to Congress at the earliest practicable date, and that the reports on the projects should include the effect of further flood control of the lower Mississippi River to be attained by the establishment of a reservoir system. In partial response to that provision, a report by the Vicksburg District Engineer on the Yazoo River and Tributaries, dated 30 May 1931 (House Document 198, 73d Congress, 2d session), concluded that there were three serious overflow problems. The first of these was overflow

from Mississippi River headwater, and its solution by the Federal Government was assured by the 1928 act. The second overflow problem was protection against Mississippi River backwater, and the least costly means of obtaining it was by construction of a levee from the end of the Mississippi River levee to the vicinity of Morgan City on the Yazoo River. However, the estimated cost of this plan greatly exceeded the benefits, hence it could not be economically justified. The third overflow problem, essentially a local matter, was protection against the overflow of the Yazoo River, augmented by tributary floods from the eastern hilly portion of the basin. The least costly comprehensive protection plan included construction of a system of retarding reservoirs, but the cost would greatly exceed the benefits and it was felt that the plan could not be economically justified then or in the prospective future. Furthermore, the report concluded that there was no Federal interest in the local overflow problem of the Yazoo River and its tributaries. No recommendation for reservoir construction was made. In a supplementary report dated 31 December 1932, adding an analysis of the unprecedented storm of 1932, the District Engineer found that the conclusions of the 1931 report were sound, and recommended no change.

Both the 1931 and the 1932 reports contemplated plans for complete protection against the maximum probable flood. In a second supplementary report dated 8 July 1933, prepared at the direction of the Chief of Engineers to consider protection against lesser floods, the District Engineer concluded, from a study of four general plans involving reservoirs and auxiliary channels, that the least costly plan would require expenditures nearly double the benefits and, for that reason, its construction could not be economically justified. The President, Mississippi River Commission, recommended that Federal assistance under the National Industrial Recovery Act be granted for construction of the auxiliary channel plan or the auxiliary channel-Sardis Reservoir plan, when and if local interests should make application therefor and otherwise comply with provisions of the act. The Board of Engineers for Rivers and Harbors, in reporting on its review of the report, stated its belief that "reservoir only" plans were preferable to those involving use of an auxiliary channel, and expressed the opinion that if any plan for flood protection were to be undertaken, it should be the seven-reservoir plan providing essentially complete protection. Concurring with the Board, the Chief of Engineers, in submitting the report on 16 November 1933 for transmission to Congress, commented that, although the physical benefits from execution of the project for local flood control as a whole did not justify the cost, the intangible benefits might warrant the execution of parts of the project. As these benefits were essentially local, he was of the opinion that any project for local flood control should be formulated and initiated by local interests to meet local needs, with reasonable Federal assistance, if warranted.

Despite these reservations respecting Federal responsibility for local flood control, the Flood Control Act of 15 June 1936 authorized the seven-reservoir plan for flood control of the Yazoo River with the proviso that the reservoirs might be located by the Chief of Engineers in his discretion, and further, that the Chief of Engineers could substitute levees, floodways, or auxiliary channels, or any or all of them, for any of the seven detention reservoirs. The 1937 act added the stipulation that the total estimated cost of the entire project should not be increased by substitution of a combined reservoir, floodway, and levee plan.

Subsequent to authorization, further study of the flood control plan led to the decision to reduce the number of reservoirs from seven to four. The sites selected for the dams were designated as Sardis, located on the Little Tallahatchie River about 11 miles northeast of Batesville; Arkabutla, on the Coldwater River, 25 miles south of Memphis and 12 miles northwest of Coldwater; Enid, on the Yocona River, 26 miles north of Grenada; and Grenada, on the Yalobusha River, 3 miles northeast of Grenada. Surveys, borings, designs, and land appraisals for the Sardis Dam and Reservoir feature began in 1935.

Clearing of the reservoir, damsite, and borrow pit areas followed in Fiscal Year 1937. The main dam was constructed principally by the hydraulic fill method, using Government plant and hired labor. A dredge, constructed at the site, excavated material in a downstream borrow pit and pumped it into the dam section. Flanking dikes at each abutment were of compacted earthfill. For regulation of storage releases, a gated outlet structure was constructed in the south dike, and a chute spillway was provided in the north abutment as a positive means of protecting the dam from overtopping in the event of an extremely large flood. Except for public-use features, construction was completed in 1940.

The designs of the other three dams followed the general form of the Sardis structures except that their embankments were entirely of compacted earthfill. The Arkabutla Dam and Reservoir Project was completed in 1943. Construction of Enid and Grenada Dams was delayed by World War II. Enid was completed in 1952 and Grenada, in 1954. The projects included relocations and adjustments of Federal, State, and local highways, railroad lines, and various utilities. Channels below the dams have been improved as features of the Yazoo Headwater Project.

The four reservoirs have a total flood control storage capacity of 3,809,800 acre-feet, ranging from 1,461,900 acre-feet (equivalent to 17.7 inches of runoff over the drainage area) for Sardis to 493,800 acre-feet (equivalent to 9.3 inches of runoff over the drainage area) for Arkabutla. Each reservoir has a small conservation (or minimum) pool, assuring a minimum lake area varying from 5,100 acres for Arkabutla to 10,700 acres for Sardis.

Studies made in connection with the Vicksburg District Engineer's report dated 30 May 1931, printed in House Document 198, 73d Congress, 2d session, concluded that there was no need for irrigation in the Yazoo Basin at that time or in the prospective future; that the then existing project was more than adequate for navigation; and that there were no favorable sites for development of hydroelectric power. Responding to requests made at a public hearing held in connection with the studies reported in House Document 308, 88th Congress, 1st session, the Vicksburg District Engineer made a study of the possibility of using existing and proposed works to provide surface-water supplies without conflict with flood control and drainage. The conclusion was that the cost of providing the requisite additional reservoir storage, plus the cost of pumping water from the streams, would exceed the cost of pumping from wells, and so the plan could not be justified.

The River and Harbor Act of 1968 modified the project for improvement of navigation on the Yazoo River, authorized by the 1875 act, to provide 9- by 150-foot navigation from the mouth to Greenwood. Although it is not a feature of the Mississippi River and Tributaries Project, the navigation project includes an increase of 600,000 acre-feet of storage in Sardis Reservoir to permit increased base flow in the Yazoo River. This will necessitate alterations of the existing spillway structure to include removal of the existing weir and construction of a tainter-gated control structure. The modification will permit utilizing part of the existing surcharge pool for navigation storage without jeopardizing the safety of the dam. No increase in elevation of the dam crest will be necessary.

Circumstances somewhat similar to those of the Yazoo reservoirs developed with respect to the Wappapello Dam and Reservoir. In a report on the St. Francis River, Missouri and Arkansas, dated 1 November 1928 (House Document 159, 71st Congress, 2d session), also made in response to section 10 of the 1928 act, the Memphis District Engineer considered a comprehensive plan of flood control. He noted that control by detention in reservoirs was feasible, but decided that a combination of levees, channel enlargements, and floodways would provide the most economical and satisfactory method of controlling the floods. However, the report concluded that, although the general plan appeared to be economically justified from the standpoint of the local interests concerned, no expenditure of

Federal funds should be authorized for the control of floods on the St. Francis River. Subsequent to that report, the local levees suffered severe additional damage due to bank caving. Having in mind the large and recurring flood losses, the Chief of Engineers concurred in the recommendation of the Mississippi River Commission that the work be undertaken by the United States, provided that local interests furnish the necessary right-of-way (House Committee on Flood Control, Committee Document No. 1, 74th Congress, 1st session). The Flood Control Act of 15 June 1936 authorized the St. Francis River Project in accordance with the recommendation, and gave the Chief of Engineers discretionary authority to modify the project to include construction of a detention reservoir for reduction of floods, provided that the estimated cost to the United States was not increased by the substitution.

After authorization, a detailed investigation was made to determine feasible methods of flood protection for the St. Francis Basin. One plan was to obtain protection by means of levees only. An alternative plan contemplated the construction of a detention reservoir to impound floodwaters, supplemented by downstream levees following generally the lines proposed under the levees-only plan, but with decreased grade and cross section. Cost estimates showed that the costs to be borne by the United States and those to be borne by local interests would both be substantially lower under the alternative plan. It was considered that the alternative plan would provide benefits at least equal to those of the levees-only plan, and would be of greater value in facilitating drainage. Construction of the detention reservoir was approved by the Secretary of War in June 1937, and contract operations on the dam, located near Wappapello, Missouri, were commenced in August 1938. This work and a highway relocation were essentially completed in 1941. The dam structure, with a crest length of about one-half mile, is composed of compacted earthfill. A gated outlet structure, provided for control of storage releases, was designed to have an outflow rate of 10,000 c.f.s. at comparatively low heads, increasing to 18,000 c.f.s. when the pool is near spillway crest elevation. A small hydroelectric plant was installed in the outlet structure to provide power for project purposes. An uncontrolled chute spillway was constructed in a saddle in the south abutment to protect the dam from overtopping in the event of an extremely large flood. The reservoir has a flood control storage capacity of 582,300 acre-feet, equivalent to 8.33 inches of runoff over the drainage area. A small conservation (or minimum) pool assures a minimum lake area of 4,100 acres.

In his report of 1 November 1928 (House Document 159, 71st Congress, 2d session), the District Engineer concluded that, because the annual rainfall over the St. Francis region is abundant and well distributed throughout the year, irrigation is not needed. He said, further, that the existing project for navigation provided for all the navigation improvement justified by then existing or prospective commerce. Although a small amount of water-power development would have been possible at three sites, the costs would make the enterprise unprofitable.

Old River Control

The Mississippi River Commission review report with respect to Old River control, dated 2 February 1954 and printed in House Document 478, 83d Congress, 2d session, formed the basis for the authorization given by the Flood Control Act of 1954. The report was not made in response to the customary congressional resolution. Section 6 of the River and Harbor Act of 1935 provided for supplementation of certain previously authorized surveys "* * * by such additional study or investigation as the Chief of Engineers finds necessary to take into account important changes in economic factors as they occur, and additional streamflow records, or other factual data." Additional streamflow records,

changed physical conditions in the general vicinity of Old River, and other data were considered sufficiently significant by the Chief of Engineers to proceed with the review under the authority of the 1935 act. The report discussed the studies which have been described previously in chapter III under "Geological Investigations," and which led to the conclusions that diversion of the Mississippi River through the Atchafalaya River was imminent and that such an eventuality must be prevented by permanent control measures. Conditions influencing the selection of types and locations of control structures were included in the discussion. In addition to giving positive assurance that they would prevent the threatened diversion, the adopted structures were required to have the capacity to regulate flow and, for the project flood, should be capable of discharging at least 700,000 c.f.s. For floods less than the project flood, the capacity should be that necessary to assure that increased frequency of operation of the Morganza and Bonnet Carré Floodways would not result. At medium stages, the structures should have sufficient capacity to approximate the natural diversion capacity of Old River under 1950 conditions. And finally, the control structures should not reduce low water flow to the extent of harming navigation or water use in the Atchafalaya Basin.

Included in the study of possible alternative plans of improvement were dams across the Atchafalaya River in conjunction with weirs, overflow dams, and notches, each of which would require construction of one or more navigation locks, and a series of nonerodible low-sill dams in the upper reaches of the Atchafalaya River that would distribute the fall in water surface over a long reach of river and eliminate the necessity for a lock. Each of these plans met a portion of the requirements, but each had serious disadvantages and none met the requirements for positive control, flexibility, safety, and economy.

The plan of improvement that evolved included two concrete control structures, each with mechanically operated gates, located on the right bank of the Mississippi River about at mile 212, above Head of Passes; an inflow channel from the Mississippi River to the low-sill structure; an outflow channel connecting the low-sill structure with Red River about at mile 12 above its mouth; a lock for navigation connecting the Mississippi and Old Rivers, together with inflow and outflow channels; an earthen dam closing Old River; enlargement and extension of main-line Mississippi River levees from Black Hawk to Torras; and bank stabilization, as required, in the Red and Atchafalaya Rivers between the outflow channel and the vicinity of Simmesport.

As designed and constructed, the low-sill structure has 11 gate bays, each with a 44-foot clear width between piers. To fulfill the various discharge requirements and to provide for flexible operation at the lowest possible construction cost, two elevations were selected for the weir crest. The three center bays have weir crests 5.0 feet below mean sea level. The weir crests in the four bays on each side of the center bays are at elevation 10.0 feet above mean sea level. Each gate bay is provided with a vertical-lift steel gate which is operated by a traveling gantry crane. The structure has a total length between abutments of 566 feet. The overbank control structure has 73 gate bays, each having a 44-foot clear width between piers. The weir crest is 52 feet above mean sea level, and the total structure length between abutments is 3,356 feet. Flow through the structure can be controlled by hinged timber panels operated by two traveling gantry cranes. Stilling basins are included in the design of the control structures. The navigation lock has a width of 75 feet, a usable length of 1,200 feet, and sills 11.0 feet below mean sea level. The roadway on the main-line levees crosses the lock on a lift bridge.

An important consideration in selecting the sites for the control structures was to insure that the diverted flow would contain bed sediment in about the same proportions as that of the Mississippi River. Analytical procedures were supplemented by hydraulic models to study, among other things, the effects of varying the alignments and shapes of the diversion channel entrance upon scour action and sediment

diversion. The conclusion was that the distribution of sediment across the adopted section would be relatively uniform.

Another important factor in site selection was to locate each structure so that it would have relatively uniform foundation conditions throughout its length and settlement would be uniform. In the initial planning of the overbank structure, a clay stratum in the foundation pointed to the need for a pile foundation to prevent detrimental settlements. However, further study developed that the foundation soils were capable of supporting the structure without use of piles. The predicted greater settlements at the abutments due to the weight of the levee were considered to warrant construction of fills at each abutment to cause consolidation of the foundation to occur before construction of the structure was begun. These preload fills eliminated nearly all the settlement under the abutting levees which otherwise might have occurred after completion of the control structure and levee. Bearing piles were required for the low-sill structure, and similar preload fills were constructed at the structure abutments to hold settlement to tolerable amounts. The preload fills were designed and overbuilt so that approximately the predicted ultimate settlements would occur in a 12-month period.

Construction of the works required for control of Old River began in September 1955 with the low-sill structure and appurtenant channels and embankments. It was believed to be prudent to schedule completion of this unit at the earliest possible time in the event that some unforeseen condition might make it advisable to close Old River completely before the project could be completed. A start on the overbank structure followed in about a year, and excavation for the navigation lock was commenced in July 1958. Both control structures, with channels and embankments, were completed in 1959, and the lock was placed in operation in March 1963.

The final major construction item, other than the highway bridge spanning the lock, was closure of Old River by a permanent earthfill dam, to prevent bypassing of the control structures. The site of the dam was dictated by the lock location; i.e., the axis of the dam was aligned with the centerline of the highway bridge. For the purpose of checking the flow of the river sufficiently that earth material would not be carried downstream as rapidly as it was placed, a submerged rockfill was placed downstream from the site of the main closure dam. At that location, the river channel was relatively narrow and riverbed materials were scour-resistant. The initial operation at the site of the rockfill dam was grading the bank slopes and placing a weighted woven-lumber mattress on the foundation area and downstream from it. This operation, completed during the 1962 low water season, provided positive protection from erosion of the riverbed and banks. Next, riprap and derrick stone were placed during the high water season of the spring of 1963. During this operation, the low-sill control structure was operated to reduce the flow in the river. The rockfill was carried to elevation 17 feet, mean sea level (m.s.l.), or higher, and the upstream face was blanketed with a 4-foot layer of stone and a 1-1/2-foot layer of clamshells for the purpose of reducing the permeability of the rockfill. When the river stage fell below the crest of the rockfill dam, the flow was substantially reduced. Construction of the main closure dam was commenced in July 1963 by pumping material from two hydraulic dredges. The sandfill was completed to elevation 45 feet, m.s.l., in the following month. The dam was completed in October 1963 with placement of hauled-in fill, which brought the dam crest to elevation 68 feet, m.s.l., and blanketed the upstream face of the hydraulic fill.

The highway bridge over the lock, with its approaches, was completed in 1965. About 4.5 miles of bank protection have been constructed at the inflow and outflow channels. Additional bank protection is to be constructed when and if the need develops. Other items remaining to complete this project consist of provision of additional scour protection in the inflow and outflow channels, provision of an

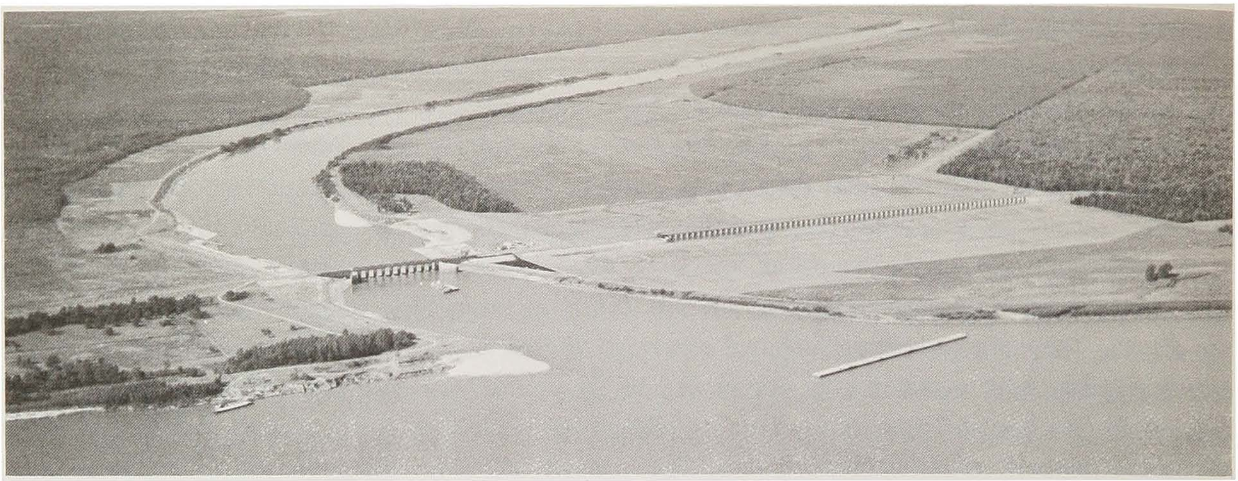


Figure 72. Old River Control Structures, Louisiana

additional gantry crane for the low-sill structure, and construction for the prevention of marine accidents at the low-sill structure. Figure 72 is a recent photograph of the control structures.

The plan of regulation by the Old River Control Structures is for the distribution of future total major flows in approximately the same proportions as those which occurred in 1950. The operation will be such as not to increase flooding in the Red River backwater area over that which would have naturally occurred had such future floods occurred in 1950.

Navigation

The 1879 act creating the Mississippi River Commission directed preparation of a plan to locate permanently and deepen the Mississippi River channel, and to protect its banks, improve navigation, and prevent destructive floods. In 1880, the Commission's first report recommended a program of regularization and bank protection for improvement of navigation on the lower river, to be supplemented by dredging where required. The contraction works proved to be inadequate, and dredging was then adopted as the channel improvement method. This alternative proved to be costly. Attention was then turned to regulation by training and contraction works and by bank protection, supplemented by dredging when necessary. Although the Flood Control Act of 1928 placed considerable emphasis on the flood control aspects, it retained navigation and channel improvement as features of the comprehensive project. The engineering plan on which the act was based called for maintenance of an improved navigation channel for river traffic not less than 300 feet wide and 9 feet deep between Cairo and New Orleans, to be obtained by dredging and training works where necessary.

A program of channel stabilization and river regulation was envisioned at a total cost of $110,000,000, to be carried out at the rate of $11,000,000 a year for 10 years. The report setting out this plan conceded that revision might be needed, as both the total cost and rate were believed to be minimum. The modification by the Flood Control Act of 1944 covered the execution in the interest of navigation and flood control of a major improvement and stabilization program between Cairo and Baton Rouge, a distance of 724 river miles, at an estimated cost over that previously authorized of $200,000,000. The Mississippi River Commission report submitting the plan expressed the opinion that the recommended stabilization might materially increase the flood-carrying capacity of the river channel and, together with

maintenance dredging, already authorized, provide a minimum channel depth of 12 feet at low water. Greater depths in crossings at low river stages are greatly desired by navigation interests because a greater margin of depth under barges reduces resistance to towing; increases speed, particularly upstream; and increases safety of navigation with the same power. At the same time, a greater margin of depth under towboats increases the efficiency of application of power.

The progress of this program has been described previously under "Channel Improvement and Stabilization." In the reach of river between Cairo and Baton Rouge, the development of the navigation channel is inseparably a part of the overall program of channel stabilization. Maintenance dredging, to provide navigable depths through crossings, is chargeable to navigation, but all other costs of channel improvement are considered to be indivisibly dual-purpose costs.

The Mississippi River channel between Baton Rouge and Head of Passes, as well as the channels through South and Southwest Passes, are not features of the Mississippi River and Tributaries Project. Between Baton Rouge and Head of Passes, the channel has natural depths and widths in excess of those required for seagoing commerce, except at a few crossings between Baton Rouge and New Orleans. The Atchafalaya and Old Rivers have been improved as a navigation feature of the project. Pursuant to authorization by the 1954 act, dredging of a channel 125 feet wide and 12 feet deep was completed in 1956. Further improvement of the Atchafalaya specifically for navigation is not planned.

The deep-draft harbors at Baton Rouge and New Orleans are not a part of the Alluvial Valley project. However, modifications of the 1928 act have been made to provide harbor improvements for barge traffic at Memphis, Greenville, Vicksburg, and Baton Rouge. The improvements consist of dredging of harbor channels and mooring areas for barges, and placement of dredge spoil so as to form flood-free areas for terminal and industrial development.

The original harbor channel for navigation at Memphis was located at the mouth of Wolf River. The project, as adopted by the River and Harbor Act of 1935, provided for a channel 9 feet deep over the lower 3 miles of Wolf River, with bottom widths varying from 250 feet at the mouth to 125 feet at Hindman Ferry Road. Although terminals with rail connections were installed along this reach, the harbor proved to be unsatisfactory in several respects. Siltation from Wolf River required heavy dredging maintenance. Major Mississippi River floods overtopped Mud Island and increased the siltation, caused current damage, and prevented terminal development along the island frontage. The harbor channel was too narrow for heavy traffic or direct handling of barges by large towboats. Even though 18 terminals were developed in the 3-mile reach, the harbor's freight-handling capacity failed to meet the needs of the expanding traffic center.

In addition to the Wolf River Harbor channel terminal development, a number of terminals were located along the 2 miles of open waterfront between Mud Island and the head of Tennessee Chute and in the upper 2 miles of Tennessee Chute. However, neither of these two reaches along the bluff bank provided land areas for heavy industrial port development. The evident need for a major harbor improvement was met by the 1946 act which provided benefits in both navigation and flood control. The site selected for the new harbor improvement was downstream from the mouth of the Wolf River where Tennessee Chute on the left bank diverged from the main channel at mile 731 and flowed southerly about 4 miles, then westerly about 4-1/2 miles to reenter the main channel at mile 722. The area between the chute and main channel is known as Presidents Island. Construction began in 1948 with hydraulic placement of a closure dam across the head of Tennessee Chute. The closure made the lower portion of Tennessee Chute available as an off-river harbor, gave highway and railroad access to Presidents Island on which was constructed an industrial fill, and protected the open-river frontage at West Memphis by

eliminating the possibility that the main Mississippi River channel might revert to Tennessee Chute. The harbor channel in Tennessee Chute from the Mississippi to the closure dam was dredged to a width of 300 feet and a low water depth of 12 feet. A new cut was also dredged across the southeast portion of Presidents Island, to the same minimum dimensions, to furnish 4 miles of navigation channel mooring and to provide material to raise the parallel industrial fill. This fill is 4 miles long and 2,000 feet wide, and provides a flood-free area of 960 acres for terminal storage and processing plants. Construction was begun in 1948 and, together with appurtenant works, including pile dikes, wave-wash protection, levee, and pumping station, was completed in 1967. The off-river harbor provides a large terminal and industrial site having both flood protection and direct access to water transportation.

The original navigation channel in Wolf River was modified in the improvement of Wolf River and tributaries as authorized by the 1958 act. Closure of the channel and diversion of the river at mile 3.5 into the Mississippi shortened the navigable channel. The portion along the Memphis front that was cut off by the channel closure, formerly exposed to siltation and strong current from Wolf River headwater floods, has become a protected slack-water harbor. The modified navigation project is complete and provides a channel 9 feet deep at low water from the Mississippi River to mile 3.0.

Under a modification of the 1928 act, a harbor project was constructed at Vicksburg by extending an approach channel from the existing off-river harbor in the Yazoo Canal. The dredged harbor channel, with minimum dimensions of 12 by 300 feet, is located contiguous to a hydraulic fill about 1,000 feet wide and 10,700 feet long. The fill has a surface area of 245 acres, and comprises material dredged from the navigation channel. The crest is above flood stage. The project was begun in 1956 and completed in 1958. The Federal Government is responsible for maintaining the navigation channels.

A project at Baton Rouge for a harbor for barge traffic (Devils Swamp) was authorized by the River and Harbor Act of 1946 and transferred to the Mississippi River and Tributaries Project by the 1948 act. The purpose was to provide both a slack-water channel and an industrial expansion area for the port of Baton Rouge. The authorization provided for minimum channel dimensions of 12 by 300 feet. A channel length of 5 miles was authorized, with the stipulation that 2.5 miles were to be constructed initially and the remainder deferred until development of the initial unit warrants such expansion. The project consisted of dredging a channel from the left bank of the Mississippi River near the northern limits of the city of Baton Rouge. The initial segment was begun in January 1958 and dredging was completed in July 1959. The River and Harbor Act of 1962 authorized the provision of suitable dikes and other retaining structures, for construction and future maintenance of the project, in order to provide additional industrial sites with water frontage needed to permit normal development and expansion of industrial and commercial activities of the locality. This portion of the project has not been completed.

The 1958 act provided for construction of a harbor and port area on Lake Ferguson, an old bendway of the Mississippi River just southwest of Greenville, Mississippi. The project, begun in 1961 and completed in 1963, included dredging a harbor and turning basin 500 feet wide and 10,000 feet long to a depth of 12 feet at lowest river stage, which is connected with the Mississippi River by a channel of the same depth, with width of 250 feet. The port area was constructed with the dredged spoil material to a width of 1,000 feet and length of 5,000 feet. The fill is about 25 feet high and forms a flood-free area of about 115 acres.

Smaller cities between Cairo and Baton Rouge have also had harbor facilities improved by the Federal Government, under section 107 of the River and Harbor Act of 1960. This legislation gives authority to the Chief of Engineers to construct small river and harbor improvement projects not specifically authorized by Congress, within prescribed cost limitations and subject to prescribed terms of local

cooperation, provided each project is complete within itself and is economically justified. The law is specifically applicable to the provision of low water access navigation channels from the existing channel of the Mississippi River to established harbor areas along the Mississippi River. Under this authority, the former waterfront of Hickman, Kentucky, was improved in 1963 by dredging a 9- by 250-foot harbor channel and turning basin in the chute behind the point bar which had masked the former open-river mooring front. Under the same authority, the port of Helena, Arkansas, was improved in 1963. Similarly, the harbor project at Lake Providence, Louisiana, was completed in 1963. This project consists of a dredged channel connecting with the Mississippi River on the west bank near mile 471, and a turning basin at the landward end of the channel. The channel is half a mile in length and provides a minimum depth of 9 feet over a bottom width of 150 feet. The turning basin is 1,000 feet long with a bottom width varying from 150 feet at its junction with the channel to 400 feet at a point 400 feet landward of the junction, and from thence a constant width of 400 feet for the remaining 600 feet of its length. The depth in the turning basin is 9 feet. Spoil from the channel and turning-basin excavation was deposited adjacent to the turning basin to provide a raised port area.

Also constructed under section 107 of the 1960 act was a small harbor project at New Madrid, Missouri. The plan of improvement included dredging a harbor channel 9 feet deep and 150 feet wide from the New Madrid Bar, mile 889 AHP, adjacent to and along the city waterfront and the New Madrid revetment for a distance of about 9,400 feet. A turning basin with 250-foot radius was provided at the downstream end of the harbor channel.

Not included with the section 107 harbor projects is the Natchez, Mississippi, port area, constructed by local interests about 2 miles downstream from the Natchez city front. The construction includes an embankment built to project levee grade extending from the hill line to the river on which are located a hard-surfaced access highway, a railroad spur, and port facilities. The embankment serves as an integral part of a levee that ties into the hill to provide flood protection for an industrial area of 250 acres. The Corps of Engineers constructed 4,000 feet of levee, joining the local interests' embankment with the hill line, and a drainage structure and pumping plant to provide interior drainage from the industrial area.

Feeder channels

The value as a navigation feature of the 724-mile channel under the Mississippi River and Tributaries Project between Cairo and Baton Rouge would be relatively minor were it not for the network of waterways which collectively form a system some 12,350 miles in length. The tributaries and connecting waterways serving the heart of the Nation reach from Pennsylvania to Oklahoma, Kansas, and Nebraska, and from the Great Lakes to the Gulf of Mexico. In 1971, this system supported a traffic movement of 303,246,248 tons, representing 129,782,686,000 ton-miles.

In addition to the Atchafalaya River navigation, which has previously been mentioned, this inland navigation system includes the upper Mississippi River; the Illinois, Missouri, Ohio, White, Arkansas, Ouachita and Black, and Red Rivers; the Gulf Intracoastal Waterway; Wolf River (Memphis Harbor); and the Yazoo River.

The upper Mississippi River extends from the mouth of the Ohio River at Cairo to Minneapolis, Minnesota, a distance by river of 963 miles. A channel 9 feet deep and 300 feet wide is maintained between the mouth of the Ohio and the mouth of the Missouri, and above the mouth of the Missouri, a 9-foot channel with adequate width for navigation is maintained to Minneapolis. Above St. Louis, a series of 29 locks and dams is required to assure project dimensions. The Illinois River reaches from

a junction with the upper Mississippi River at Grafton, Illinois, to Chicago Harbor at Lake Michigan, and provides about 363 miles of channel with minimum dimensions of 9 feet deep and 225 feet wide. Nine locks and dams are provided. The Missouri River Navigation Project includes a channel 9 feet deep and 300 feet wide from the confluence with the upper Mississippi River just above St. Louis to Sioux City, Iowa, a distance of about 735 miles. The Ohio River Project extends from the confluence with the Mississippi at Cairo to Pittsburgh, a distance of 981 miles. The project channel is 9 feet deep and of adequate width (400 to 600 feet), with locks and dams. The existing project is being modified to reduce the number of locks and dams from 43 to 19. The Green River, which has been improved for slack-water navigation, enters the Ohio River about 8 miles above Evansville, Indiana. At Pittsburgh, the Ohio River forks into the Allegheny and Monongahela Rivers. A channel 9 feet deep and 200 feet wide from Pittsburgh to East Brady, Pennsylvania, 72 miles, is provided by eight locks and dams on the Allegheny River. From Pittsburgh to Fairmont, West Virginia, a distance of 129 river miles, a channel 7 to 9 feet deep and 300 feet wide is provided by 11 locks and dams on the Monongahela River.

The White River enters the Mississippi River about 65 miles below Helena, Arkansas. The existing project provides for channel maintenance between the mouth of the river and Batesville, Arkansas, by snagging, dredging, and contraction works. At present, a navigation channel 5 feet deep by 125 feet wide is maintained below Augusta, Arkansas. In April 1971, the Chief of Engineers authorized resumption of maintenance of a 4-1/2- by 100-foot channel between Augusta and Newport, Arkansas.

The navigation route of the Arkansas River begins at the confluence of the White and Mississippi Rivers, proceeds about 10 miles via the White, through the Arkansas Post Canal, the Arkansas River, and the Verdigris River, to Catoosa, Oklahoma, a distance of about 450 miles. The project, nearing completion, will have a minimum channel depth of 9 feet, with channel widths of 300 feet on the Arkansas Post Canal, 250 feet on the Arkansas, and 150 feet on the Verdigris. There will be a series of 17 locks and dams.

At present, a channel 6-1/2 feet deep and 100 feet wide is maintained on the Ouachita and Black Rivers below Camden, Arkansas, a distance of 351 miles, through the Ouachita, Black, and Red Rivers, to the junction of Old and Atchafalaya Rivers. A modified project, now under construction, provides for enlarging the channel dimensions to 9 by 100 feet and replacing the six existing locks with four larger locks.

The existing project on the Red River below Fulton, Arkansas, has no specifically authorized channel dimensions, but below the mouth of Black River, a 9- by 100-foot channel is maintained. The project for the Red River Waterway, authorized by the River and Harbor Act of 1968, provides for a 9- by 200-foot navigation channel extending about 294 miles from the Mississippi River through Old River and Red River to the vicinity of Shreveport, and then through Twelvemile and Cypress Bayous to a point near Daingerfield, Texas. Nine locks will be required. Construction has not been started.

At New Orleans, the Mississippi River connects with the 1,109-mile-long Gulf Intracoastal Waterway which provides a 12- by 125-foot navigation channel west to the Mexican border and east to Apalachee Bay, Florida. Work has not yet started on the increase to a 16- by 150-foot channel from the Mississippi River to the Houston Ship Channel, authorized by the River and Harbor Act of 1962. A connecting channel 12 by 125 feet, about 64 miles long, is maintained from Morgan City to Port Allen, opposite the lower limit of the Port of Baton Rouge.

The Wolf River (Memphis Harbor) Project has previously been described, as has also the recently authorized project on the Yazoo River.

Developments in modern towboats and barges

Until the early 1930's, most of the towing vessels on the Mississippi River system were steampowered, with stern paddle-wheel propulsion. Barges were relatively small and had been designed for deckloading, or with hoppers. Many wooden coal barges remained in service. In the early 1930's, important developments in the design, power, and efficiency of towboats and in the design and capacity of barges began to occur. Some of the older steampowered towboats were converted from coal to fuel-oil burners, and some of the sternwheelers were converted to screw-propelled boats. With development and perfection of the marine diesel engine, many applications to shallow-draft towboats were investigated. The Federally subsidized bargeline pioneered many of the early developments. Modernization of its fleet encouraged private capital to invest in bargeline equipment, and to engage in towing services. Movement of petroleum products by barge added stimulus to the development of modern, efficient towing vessels and barges. Soon, additional commodities were moving by barge: finished steel products from the industrialized regions of the country, and grain and grain products from the midwest agricultural areas to southern ports. In 1972, heavy commercial traffic, including coal and coke, petroleum products, nonmetallic minerals, metal products of all kinds, building materials, salt, sulphur, and chemicals, as well as grains and petroleum products, is being moved over the inland waterways system by towboats and barges.

Modern towboats are built to precise specifications and are equipped with sophisticated navigational instrumentation and safety devices, in contrast to the stern- and side-wheel steamers which formerly plied the navigable waters of the Mississippi River and its tributaries. They range from single-screw propelled vessels to those with three and even four propellers, each screw being driven by an individual diesel engine. The largest towboats have four screw propellers with a total of 9,000 horsepower, and each towboat is capable of pushing 40 barges, fully loaded with as much as 50,000 tons of cargo. Such craft have lengths of 170 feet, beams of 54 to 58 feet, and drafts as much as 10 feet 3 inches. Three common smaller sizes of towboats in service in 1972 are 117 to 160 feet long, 30 to 40 feet wide, 7.6- to 8.6-foot draft, and are rated at 1,000 to 6,000 horsepower.

Adoption of the screw propeller as a replacement for the sternwheelers created a problem with respect to the propeller size because of the small available clearance between the bottom of the towboat and the channel bottom. The problem was solved by development of more efficient propellers and by designing hull construction with a tunnel stern. The tunnel stern design feature places part of the screw propeller in a spoon-shaped recess in the bottom of the hull, above the water-surface level. The recess is filled with water by vacuum action when the propeller is turning. Another device introduced to improve propeller efficiency is the Kort nozzle. This venturi-shaped device is designed to surround or shroud the propeller, thereby concentrating the flow of water both entering and leaving the propeller. The Kort nozzle has been credited, under favorable operating conditions, with adding as much as 20 percent to the thrust developed by the propeller.

Other improvements incorporated in the modern diesel towboat include electric steering controls which actuate hydraulically operated steering engines to control the rudders. Engine controls in the pilothouse include a combination of clutch, reverse gear, and throttle which provide the pilot control of engine speed, direction of rotation, and power output. These permit faster and more precise handling of the propelling engines with resulting timesaving in maneuvering. Electronic communication systems and navigational aids have been adapted to the modern river towboat. They include a wide variety of radio communication channels for both ship-to-ship and ship-to-shore transmission. The ship-to-shore circuit can be patched into the shore telephone circuits so that the pilot on watch can keep in touch

with his home office through two-way radio and telephone hookups. Ship-to-ship communications permit safer operation between vessels passing or overtaking each other on the river. Radar equipment has been installed on most modern towboats to assist the pilot in night navigation and during periods of inclement weather resulting in reduced visibility. Radar permits the pilot on watch to observe the movement of other vessels in the vicinity and to pick up the outlines of bridges, wharves, moored vessels, floating navigational buoys, and other aids to navigation.

In the continuing effort to improve efficiency, the design of towboat hulls has received added attention through exhaustive model tank tests performed both in the United States and in Europe. Tests have included self-propelled model towboats built to a scale ratio of 1:10, together with an accompanying flotilla of barges. Standard practice includes model tests before the design is finalized in every instance of radical departure from conventional design. Because reduction of resistance to towing is important to the barge operator, the lines and configuration of barges have received similar attention from the naval architect.

The inland waterways industry has developed a wide variety of types and sizes of barges for efficient transportation of bulk and outsize cargo. The cargo may range from coal in open hopper barges to chemicals in special tank barges, grain in covered barges, to stone and steel products on flat-deck barges. Assemblies too large for rail or highway transport are frequently shipped by barge. In the early 1940's, most barges were designed as individual units having a rake section at bow and stern. For navigating singly, this configuration is still quite efficient. However, model tests have shown that the arrangement of multiple units of this form in a single tow will result in considerable loss of efficiency caused by the cumulative drag of the water-breaking rakes in the body of the tow. Series of barges have been designed to be assembled into integrated tows, having an underwater shape nearly equivalent to that of a single vessel. The integrated assembly is made up of several barges with the lead barge having a long, easy rake at the bow to minimize towing resistance. The lead barge has a square stern to abut the next intermediate barge, also with a square bow and stern, which tends to eliminate any underwater surface break when the barges are loaded to the same depth. The trailing barge in the integrated tow has a short rake at the stern, and the bow is square in order to fit the square ends of the intermediate barges. Water resistance of the integrated tow is very nearly the equivalent of the smooth underwater lines of a single vessel of equivalent total length. The integrated high-speed tow is very efficient in the transportation of petroleum products and other commodities in large volumes when transported over long distances on a continuing basis. Substantially identical draft of all barges in the tow is vital to the efficiency of towing.

The hopper barge is doubtless the most versatile, least costly, and most numerous of all barge types of the inland waterway fleets. With minor modifications, it can be adapted to transportation of many types of solid or packaged cargo. The open hopper barge is utilized for transportation of a wide range of cargo which needs no protection from the elements. These barges have been constructed in three widely used sizes: 1,000-ton capacity, 175 by 26 feet, with 9-foot draft; 1,500-ton capacity, 195 by 35 feet, with 9-foot draft; and 3,000-ton capacity, 290 by 50 feet, with 9-foot draft. The open hopper barges are generally of welded plate construction, with double bottoms for greater safety, and heavy-framed inside to absorb the impact of loading and unloading by the bucket method.

The covered, dry-cargo barge serves a wide variety of shipping requirements in providing for the transportation of bulk-loading commodities which require protection from the elements. These barges differ from the open hopper barges only in that they are fitted with watertight covers over the entire cargo space. The most generally used sizes on the Mississippi system are the 1,000- and 2,000-ton-capacity

barges, with dimensions and draft as for the open hopper barges described above.

Tank barges for the transportation of liquid cargo may be of the single-skin or double-skin type, or they may have independent cylindrical tanks. Hydrodynamic considerations require that the hulls of the first two types be compartmentalized by means of intermediate bulkheads. In the single-skin type, all hull structural framing is exposed inside the cargo compartments, whereas with the double-skin tank barge, the inner shell forms the cargo compartments and is free of appendages, rendering it easier to clean and line. Barges having independent cylindrical tanks are used for transportation of liquids under pressure or in cases where pressure is utilized to discharge the cargo. The tank barge sizes correspond to those of the hopper barges previously described.

Machinery, vehicles, heavy equipment, stone, pile timbers, and pipe products used by the petroleum and natural gas industry are frequently transported on deck barges if there is no requirement for protection from the elements. Deck barges are utilized by the construction industry as work barges; construction equipment, such as draglines and clamshell bucket machines, are mounted on the deck when flotation is available at the construction site. There are also various special-purpose barges in use, including car ferries for from 10 to 20 railroad cars, special types of dump scows, and self-unloading barges for bulk cement and grain.

Development of dredges

As with towboats and barges, the early 1930's marked a period of transition in design of the dustpan dredges described by Elliott. The side-wheel-propelled dredges with steam-reciprocating engines came to be superseded by steam-geared turbine prime movers for dredge pump operation, with twin-screw steam engine propulsion. The early side-wheel steam dustpan dredges, such as the Iota, Kappa, Flad, and Harrod, were very slow in propulsion and had somewhat limited power through their steam-reciprocating engines which drove the double-suction dredge pumps. The Iota, Kappa, and Flad had 30-inch-diameter discharges, and the Harrod's was 34 inches. Power on the main dredge pump was about 1,000 indicated horsepower, and dredge capacity ranged from 1,500 to 2,000 cubic yards per hour.

The Potter and Ockerson, modernized dustpan dredges placed in service in 1932, had steel hulls, approximately 215 by 46 by 9 feet, with steel deckhouses and upper works. Prime mover for the single-suction 32-inch-diameter discharge dredge pump was a geared multistage steam turbine of approximately 1,400 brake horsepower. Propulsion was provided through twin screws, each powered with a vertical triple-expansion steam engine of about 900 indicated horsepower. These dredges were initially designed for a digging depth of 20 feet below the water surface. In later years, the hulls were lengthened to 234 feet and the ladders were lengthened for a digging depth of about 30 feet below the water surface. The dredges operate most efficiently with not more than 900 feet of floating discharge pipe, and their capacities in terms of solids moved is from 2,500 to 3,000 cubic yards per hour.

Two years later, the dustpan dredges Jadwin and Burgess were placed in service. They are similar to the Potter and Ockerson, though somewhat larger and more powerful. Their steel hulls are 250 by 52 by 9 feet with steel deckhouse and upper works. The 32-inch-diameter discharge single-suction dredge pumps are driven by steam-geared turbines, developing a normal rating of about 2,100 brake horsepower with provision for overloading to approximately 2,400 brake horsepower. Propulsion is substantially the same as that for the Potter and Ockerson. With additional power on the dredge pump, the dredges Jadwin and Burgess have production capacities of from 3,500 to 4,000 cubic yards per hour. The ladders of these two dredges were initially long enough to permit dredging to a depth of 32 feet below the water surface.

All four of the dustpan dredges just described were planned for operation in the Memphis District. In 1950, the Jadwin was transferred to the Vicksburg District, and in 1966, its hull was increased to 274 feet and its ladder lengthened to increase the dredging depth capability to about 60 feet below the water surface. This capability permits the dredge to be used, approximately 2 months each spring, on channel maintenance work on the seven or eight crossings on the Mississippi River immediately downstream from Baton Rouge, where a 40-foot navigable channel has been established. The work below Baton Rouge is in addition to the normal channel maintenance dredging in the Vicksburg District.

In the early and mid-1930's, channel maintenance and realignment were undertaken by a series of pump barges, at that time peculiar to the Mississippi River. They were originally designed to operate as agitator dredges, with the effluent discharging overboard without pipeline. It was envisioned that they could be towed in pairs by a powerful towboat and utilize the conventional hopper dredge type of side suction with a tunnel-shaped suction head termed a "draghead," which moved along the bed of the stream to loosen the material. Suction pipes were of sufficient length to provide dredging depths of from 30 to 50 feet. At a later date, one of the pump barges was converted for dredging depths of about 90 feet. Pump barges 1 and 2 were built in 1933 on standard 120- by 30- by 7-foot steel deck barges. The dredge pumps were the conventional 30-inch-discharge hopper-dredge type driven by a vertical, triple-expansion steam engine of 1,000 indicated horsepower. Agitation dredging was tried extensively but after thorough experimentation, the method was deemed to be definitely unsuited to the Mississippi River. This was attributed to the fact that the predominant material encountered was sand, which is too heavy for the river currents to transport a sufficient distance to accomplish the purpose of dredging the channel.

Later, the two pump barges were modified so that they could be operated much the same as the dustpan dredges. An additional pair similar to the first two was constructed late in 1933, and a fifth one was built in 1934. All five of the barges were operated intermittently in the Vicksburg and New Orleans Districts until the late 1940's, when they were all withdrawn from service.

The dustpan dredge, though effective in maintaining a project channel during low stages, proved to be inferior to the cutterhead dredge in making new channels and correcting and realigning old channels where the discharge must be spoiled overbank, or where dikes or fills are part of the structure. The cutterhead dredge is suitable for excavating in material such as sand, clay, buckshot, heavy and compacted gravel, and soft rock. At the lower end of its suction pipe ladder, a revolving cutter, made up of heavy blades, and sometimes, teeth, is fitted. This cutter is lowered to the bed of the stream where its revolving blades bite into the material to be dredged, loosening it so it can be raised by suction to the pump. Normally, a dredge of this type discharged through a pipeline of some length in order to deposit the dredged material at the desired location. The distance and lift through which the material can be moved are limited principally by the pump horsepower, although, of course, the weight of the material being handled is likewise a factor.

In the early 1930's, several small cutterhead dredges were still being operated by hired labor in the three Mississippi River Commission Districts. They were employed principally in the maintenance of harbors and in some channel improvement dredging. During the 1930's, considerable dredging activity was undertaken in the Atchafalaya Basin, using Corps-owned cutterhead dredges from other Corps offices. With the availability of powerful contractor-owned cutterhead dredges of modern design, by the early 1940's, the Corps-owned dredges had all been disposed of by sale or transfer.

The contractor-owned cutterhead dredges were used extensively in the cutoff and channel improvement program on the lower Mississippi and the Atchafalaya Rivers. During the period that the

Corps of Engineers was curtailing its hired labor cutterhead operations, various dredge contractors operating in the lower valley began a program of modernizing their older dredges and building new ones. The first major contract operations were performed by such dredges as the George W. Catt, the Cartagena, and the Lake Fithian. These all had 27-inch-diameter discharges and were steampowered with up to 4,000 horsepower available for the dredge pump. All had steel hulls and none were self-propelled. Later, the steampowered geared-turbine dredge G. A. McWilliams became available as a contract piece of dredging equipment for channel rectification and realignment dredging projects throughout the lower valley. Development also began on a family of cutterhead pipeline dredges employing various combinations of diesel and diesel-electric power as prime movers. This group includes the Duplex, with 3,650 horsepower, and the Windham, with 4,000 horsepower.

In the late 1950's and early 1960's, dredging contractors undertook to rebuild and repower their older dredges and likewise to design and build new cutterhead dredges to the most modern design. Included in this group are the BDCO No. 32, a 27-inch diesel and diesel-electric dredge with approximately 4,500 horsepower on the main pump and having a 27-inch-diameter discharge. A formerly Corps-owned Missouri River dredge, the Captain William Clark, was rebuilt with about 7,000 horsepower through a geared steam turbine as drive for the 30-inch-diameter discharge dredge pump. This was originally a side-wheel, self-propelled dredge, but all propelling machinery and equipment were removed at the time of rebuilding. The dredge Paul F. Jahncke was rebuilt on the hull of a former Corps of Engineers dredge, the 24-inch-diameter discharge pump being powered through a 3,750-brake-horsepower diesel engine. Other large contractor-owned dredges operating on the lower river for the Corps of Engineers included the diesel dredge Western Scout, with 3,500 horsepower, and the Warrior, with 3,000 horsepower. During this rebuilding and modernizing of dredges, there were evolved many improvements which resulted in more efficient and economic operation.

Navigation traffic

The River and Harbor Act of 23 June 1866 required the Secretary of War to state in his annual report "* * * what amount of commerce and navigation would be benefited by the completion of each particular work: Provided, that he shall continue to make such a report at the commencement of every session of Congress until the works herein provided for shall all be completed * * *." The works provided for included a large number of harbor improvements and improvements of inland waterways, many of which were of such nature that work continued to be necessary from time to time to maintain the project dimensions. The same provision of law was contained in later river and harbor acts, and the act of 22 February 1891 gave the War Department authority to collect the figures needed for compiling these statistics. The act provided "* * * that owners, agents, masters, and clerks of vessels arriving at or departing from localities where works of river and harbor improvement are carried on shall furnish, on application of the persons in local charge of the works, a comprehensive statement of vessels, passengers, freight, and tonnage." Section 2 of this act stipulated that every person or persons offending against the provisions of the act would be liable to a fine of $100, or imprisonment not exceeding 2 months. The River and Harbor Act of 1922 strengthened the 1891 law and exempted information on rafting of logs unless specifically requested. The River and Harbor Acts of 1910, 1911, and 1912, directed the Corps of Engineers to adopt a uniform system of classification for freight, and to collate ton-mileage statistics upon rivers and inland waterways as far as practicable. The acts of 1909 and 1913 required reports relating to the existence and establishment of both private and public terminal and transfer facilities contiguous to the navigable water proposed to be improved, and other matters

considered to have a bearing upon the improvement of navigation.

The statistics on waterborne commerce, collected, compiled, and published in accordance with law, were designed to meet the administrative requirements of the Corps of Engineers in connection with duties imposed upon it by Congress, and also proved to be of interest and value to commercial and shipping concerns. A uniform system of classification for freight, the Commodity Classification for Shipping Statistics, was devised through cooperation of all Federal agencies engaged in water-shipping activities. Due to increased interest in waterborne commerce and the great demand for information on the subject, it was decided in 1919 to publish in a separate volume of the Annual Report of the Chief of Engineers the commercial statistics which had previously been printed with reports of the District Engineers. This procedure continued until 1953, when the statistics were published in four parts, each of which contained complete coverage within a specific geographic area. Those for the waterways and harbors of the Gulf coast, the Mississippi River system, and Antilles are published as Part 2.

The figures recorded annually in the publications depict the increasing importance of the Mississippi River as an artery of commerce (see figure 73). In 1931, the net total internal freight traffic between

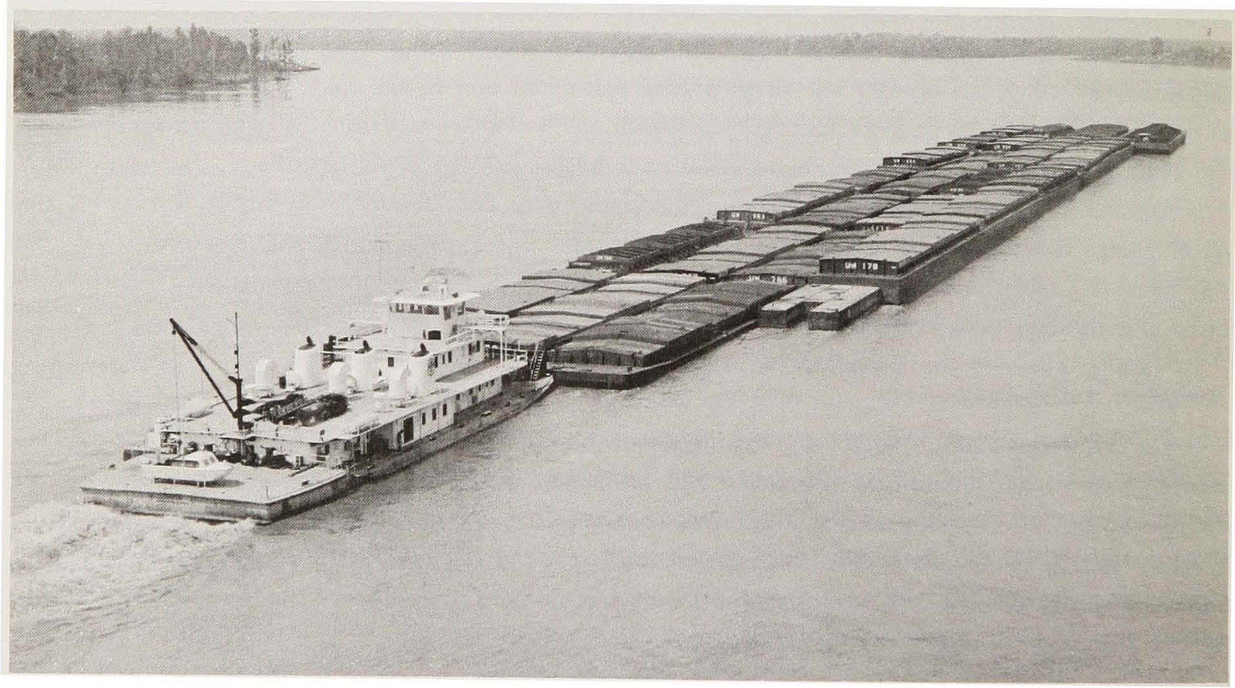


Figure 73. Typical large tow plying 9-foot navigation channel, lower Mississippi River

Minneapolis, Minnesota, and mouth of Passes was 15,628,284 tons. Influenced by World War II, the figure rose to 44,671,316 tons in 1944, when the principal commerce included the upstream movement of gasoline, oil, sulphur, and other products needed in the war effort, and the downstream movement from inland shipyards of Army and Navy craft for use in the war effort. The tonnage figures decreased somewhat in 1945 and 1946, then began a steady climb, reaching 66,922,594 tons in 1950, 128,347,795 tons in 1960, and 250,821,603 tons in 1970. The corresponding figures for the Mississippi River system are, of course, greatly in excess of those for the internal traffic, as they include both foreign and domestic commerce. The principal commodities by tonnages in 1970 include petroleum and products (39 percent), grain and farm products (15 percent), coal and coke (11 percent), and chemicals and allied products (9 percent). In addition to the commercial cargo traffic, many pleasure craft from

all parts of the country use the Mississippi River for vacation and travel.

For the Atchafalaya River, from Old River Lock at the Mississippi River through Old River and via the Atchafalaya River to Morgan City, the traffic figure reached 6,466,704 tons in 1959, decreased to 3,938,999 tons in 1967, and increased each year thereafter to reach 4,905,034 tons in 1970. In that year, 65 percent of the traffic was northbound. Petroleum and products and industrial chemicals are the predominant commodities of commerce.

Real Estate Procurement

Although section 2 of the Flood Control Act of 15 May 1928 stipulated that no local contributions to the adopted project were required, section 3 prescribed that no Federal funds appropriated under authority of the act should be expended on construction of any item of the project until the States or levee districts had given assurances that they would provide, without cost to the United States, all rights-of-way for levee foundations and levees on the main stem of the Mississippi River between Cape Girardeau, Missouri, and the Head of Passes. On the other hand, section 4 placed on the United States responsibility for providing flowage rights for additional destructive floodwaters that will pass by reason of diversions from the main channel of the Mississippi River; authorized acquirement by condemnation of lands, easements, or rights-of-way needed in carrying out the project; and provided that benefits to property from execution of the flood control plan should be taken into account in determining the amount of compensation to be paid. Moreover, an opinion of the Attorney General of the United States, dated 8 June 1933, made the United States responsible for payment for rights-of-way for levees in the Atchafalaya Basin and on the south sides of the Arkansas and Red Rivers. Procurement of lands, easements, and rights-of-way for navigation improvements is also a responsibility of the Federal Government.

The obligation of local interests to furnish lands, easements, and rights-of-way for the modified and expanded project free of costs to the United States has been changed from time to time by acts of Congress. Section 4 of the 15 June 1936 act stipulated that the States or other qualified agencies would make all alterations of highways made necessary by construction of the authorized reservoirs. However, as previously noted, the authorization further provided for modification of the St. Francis plan, consisting of levees, channel enlargement, and floodways, to include a detention reservoir, in which event the United States would be responsible for lands and flowage necessary for construction, except for flowage of highways. Section 2 of the act of 1938 provided that, in the case of any dam and reservoir project or channel improvement or channel rectification project for flood control, authorized by the act of 1928, as amended, by either of the two 1936 acts, and by the 1938 act, title to all lands, easements, and rights-of-way necessary for such project shall be acquired at Federal expense. This change affected the dam and reservoir projects for flood control in the St. Francis and Yazoo River Basins. In section 3 of the 1941 act, under subparagraph (d) of the Lower Mississippi River item, provision was made for reimbursement of local authorities for expenditures for providing rights-of-way and flowage easements required for future setbacks of main-line Mississippi River levees. This was modified by the 1944 act to stipulate that the provision would be construed to authorize reimbursement for the actual market value of lands, rights-of-way, and easements furnished subsequent to 18 August 1941 (the date of enactment of the 1941 act) for setbacks of main-line Mississippi River levees, regardless of State laws limiting payments to local tax assessment valuations for the previous year. The 1946 and 1951 acts further modified the requirements affecting the works authorized in the St. Francis Basin, the White River backwater area, and the Yazoo River Basin by relieving local interests of all requirements, except

maintenance of levees as required under section 3 of the 1928 act, constituting a relief from requirements to provide, without cost to the United States, lands, easements, and rights-of-way for construction of the projects, and maintenance of certain channels in the St. Francis Basin.

Thus, the several legislative provisions have resulted in local cooperation requirements varying from no responsibility in some instances to considerable responsibilities in others. Local interests have furnished rights-of-way for all main-stem levees along the Mississippi River, and they furnish rights-of-way for setbacks of these levees subject to Federal reimbursement. Rights-of-way for floodway levees are also furnished by local cooperating agencies, subject to reimbursement in accordance with the Flood Control Act of 1934. The Federal Government has acquired flowage easements over lands in the floodways and title to lands required for construction of control structures. The only departure from this pattern for the main-stem features has been in the case of modification of the lower section of the Birds Point-New Madrid Floodway Project to reduce flood overflow in the Mississippi River backwater portion of the floodway. In this instance, the required local cooperation included furnishing, without cost to the United States, all lands and rights-of-way necessary for construction of the improvement; and flowage rights and easements over, upon, and across lands and properties within the backwater area of the floodway, covering the temporary ponding of interior runoff and use as an emergency floodway, if necessary. For construction dredging in the Atchafalaya Basin Floodway, perpetual dredging and spoil-disposal easements were acquired. Easement or other title to riverbank land required for bank protection work is not normally acquired. Construction permits covering narrow work area strips adjacent to the caving banks are obtained by the Government, provision being made to compensate the owners for any damage to improvements, crops, or timber. For the harbor improvements at Memphis, Baton Rouge, Vicksburg, and Greenville, local interests furnished, at their cost, all lands, easements, and spoil-disposal areas required for construction and maintenance.

Numerous deviations from the main-stem pattern exist in the requirements with respect to the tributary projects. The Ohio River levees in the Mounds-Mound City area, built under the 1938 act, were subject to the standard local cooperation requirements, but have been improved as part of the main-line system under the 1928 act. Channel improvements authorized in the L'Anguille Basin and on the west Tennessee tributaries are subject to provision of lands, easements, and rights-of-way at local cost. The White River backwater levee was subject to special conditions based on occasional flooding of the area as an emergency reservoir. Local interests were required to provide lands, easements, and rights-of-way for the levee, including easements and storage rights to permit flooding of the protected area as an emergency reservoir. Between 1936 and 1951, local interests, at considerable expense, met all requirements of local cooperation except provision of right-of-way for a section of levee in the vicinity of Old Town Lake. By the 1946 and 1951 acts, as previously mentioned, the requirements were modified to limit cooperation therefor to ordinary maintenance of levees. When the project was changed by addition of a pumping plant, local interests were required to provide the right-of-way. Levees on the White River between Augusta and Clarendon and local protection at DeValls Bluff were originally authorized under Flood Control, General, but were later incorporated in the basic 1928 project. The channel improvements in Cache River and Bayou DeView, and the channels in the Bayou Meto Basin and the pumping plants and canals for the Grand Prairie Region were all authorized subject to provision of rights-of-way by local interests, as were also the local protection works at Des Arc and the levees to protect the area in Jefferson Parish from storm tides in Lake Pontchartrain. Local interests were relieved of the obligation to furnish rights-of-way for the north-bank levees of the Arkansas River and the Yazoo and Red River backwater levees, and for major channel improvements in the Big Sunflower and the Boeuf-Tensas Basins.

However, the authorization of the diversion channel for the Bayou Rapides, Boeuf, and Cocodrie Project required provision of rights-of-way by local interests.

The policy consistently applied for the Mississippi River and Tributaries Project has been to acquire only those lands and interests therein required for construction, operation, and maintenance of the project, reserving to the landowners, their heirs, and assigns all rights that would not interfere with the works. The type of interest has necessarily depended upon the type of structure and upon operational requirements, as well as upon the policies of Congress set out in the authorizing acts. For levees, channel improvements, and major drainage improvements, right-of-way easements or servitudes are required. An exception occurs when, due to local custom or State statutes under which the levee districts function, local levee districts acquire fee title to levee rights-of-way. Flowage easements are acquired over lands required for new floodways or modifications to existing floodways. When necessary because of operational and maintenance requirements, as with the Morganza Floodway, comprehensive flowage easements imposing restrictions on future uses of floodway lands are obtained. An exception to this policy is the Bonnet Carré Floodway, the entire area of which was acquired in fee because it was decided that the United States needed absolute control of the area for operational and maintenance purposes.

Fee title is acquired for structures and other permanent installations, including pumping plants, major drainage structures in levee lines, dams, outlet works, and spillways. Fee title also has been obtained for lands to be permanently or intermittently inundated by operation and maintenance of a reservoir, for lands needed to provide public access, and for lands required for mitigation of fish and wildlife losses.

At the Wappapello and Sardis Projects, taking lines for fee acquisition were established along the perimeter of the reservoirs by blocking out entire ownerships. In this way, considerable lands were acquired above the expected maximum flood control pool elevation. A different rule was applied in the case of the Arkabutla Project, where the taking line was established along an elevation that provided for sufficient freeboard above the maximum contemplated flood control pool and for the acquisition of flowage easements in certain areas above the conservation pool, where only intermittent flooding would occur. In the case of the Enid and Grenada Projects, the policy set was to acquire fee title to those lands to be permanently or intermittently inundated as a result of operation and maintenance of the reservoir, and to such additional lands as needed to provide for public access. The taking lines were based on a guide contour line, taking into consideration the static full pool elevation plus a variable flowage freeboard height to provide appropriate allowances for induced surcharge operation of the reservoir.

In 1953, after completion of these five reservoirs, a Corps-wide policy was adopted to limit fee acquisition in reservoir areas to those lands lying below the 5-year-flood-frequency level. Additional lands needed for flowage were obtained by acquisition of an easement interest. The upper flood line was established on the basis of the right to flood to a designated ground elevation. In 1962, a joint policy adopted by the Department of the Army and the Department of the Interior modified the 1953 policy by declaring that, to the extent permitted by law, it is the policy to acquire adequate interest in lands necessary for realization of optimum values for all purposes, including additional land areas to insure full realization of optimum present and future outdoor recreational and fish and wildlife potentials of each reservoir. The policy includes fee title acquisition of lands necessary for permanent structures; of lands below the maximum flowage line of the reservoir, including lands below a selected freeboard where necessary for protection from the effects of saturation, wave action, and bank erosion, and to permit induced surcharge operation; and of lands needed to provide for public access or for operation and

maintenance of the project. Fee title is also to be acquired to additional lands needed to meet present and future requirements for fish and wildlife as determined pursuant to the Fish and Wildlife Coordination Act, and to lands needed to meet present and future public requirements for outdoor recreation, as authorized by Congress. As yet, no reservoir for the Mississippi River and Tributaries Project has been constructed under this new acquisition policy.

The method employed in acquisition depends upon whether title is to be vested in the United States, or in the local cooperating agency. If the authorizing legislation makes no requirement of local cooperation, the necessary title is acquired by the Federal Government and is vested in the United States. If operation and maintenance of the completed work is a local-interest responsibility, the local cooperating agency acquires the right-of-way and makes it available to the Government for construction, but retains title. If the authorizing legislation makes payment for right-of-way a Federal responsibility and maintenance an obligation of local interests, the local cooperating agency acquires the right-of-way and retains title thereto, subject to reimbursement of cost by the United States, pursuant to the acts of 1934, 1941, and 1944.

The Land Acquisition Policy Act of 1960 (Public Law 86-645—86th Congress) declared it to be the policy of Congress that owners and tenants shall be paid a just and reasonable figure for their property if it is acquired for public works projects. It prescribes a procedure for dissemination of information, to owners and occupants in and adjacent to the project area, as to the probable timing for the acquisition of lands for the project and for incidental rights-of-way, relocations, and other requirements affecting owners and occupants. One result of this modification was substitution of a procedure calling for practical and realistic negotiations based upon prevailing market prices for the so-called "one-price policy."

Section 209 of the Flood Control Act of 1968 made provision for Federal assistance to State and local agencies if the State has been unable to secure lands or interests therein as sites for resettlement of families, individuals, and business concerns displaced by a river and harbor, flood control, or other water resource authorized project. If it has been determined by the Secretary of the Army that the State is unable to acquire the necessary lands with sufficient promptness, the Secretary, upon request of the Governor, may acquire them by purchase, donation, condemnation, or otherwise.

Enactment on 2 January 1971 of the Uniform Relocation Assistance and Real Property Acquisition Policies Act of 1970 (Public Law 91-646) modified the foregoing act. It provides for uniform and equitable treatment of persons displaced from their homes, businesses, or farms by Federal and federally assisted programs, and establishes uniform and equitable land acquisition policies for Federal and federally assisted programs. The purpose of establishing a uniform policy for relocation assistance is to insure that displaced persons shall not suffer disproportionate injuries as a result of programs designed for the benefit of the public as a whole. Provision is made for payment to any displaced person for actual reasonable expenses in moving himself, his family, business, farm operation, or other personal property, for actual direct losses of personal property as a result of moving or discontinuing a business or farm operation, and for actual reasonable expenses in searching for a replacement business or farm. In lieu of such payments, any eligible person displaced from a dwelling may elect to receive a moving expense allowance and a dislocation allowance, and if displaced from his place of business or farm operation, may receive a fixed payment in an amount based on the average annual net earnings of the business or farm operation, within stated limitations. The act also provides for additional payments to homeowners and tenants who are displaced from dwellings occupied by them for stated minimum periods, and for relocation assistance advisory services. Whenever real property is acquired by a State agency and furnished as a required contribution incident to a Federal program or project, acceptance by the Federal agency concerned is

contingent upon the making of payments and provision of assistance by the State as required of a State agency by the act. The uniform policy on real property acquisition practices establishes guidelines aimed at the expeditious acquisition of real property by negotiation, prescribes the conduct of negotiations, and prescribes the procedure in the event of condemnation.

Table 2 shows by project features the extent of total Federal acquisitions in fee and in easements.

Table 2

Total Federal Acquisitions in Fees and Easements Through 30 Jun 1972

Project Feature	*Fee*		*Easement*	
	Acres	*Cost*	*Acres*	*Cost*
Atchafalaya Basin	345	$ 9,973	106,223	$ 1,817,470
Morganza Floodway			71,577	1,156,397
West Atchafalaya Floodway			154,348	1,057,285
Bonnet Carré Spillway	7,697	757,898	127	5,213,651*
Old River Closure	2,979	114,339	9,597	160,195
Birds Point-New Madrid Floodway			110,025	1,922,795
Channel Improvement	1,027	217,313	31,636	1,268,398
Mississippi River Levees	142	12,400	982	525,400
St. Francis Basin	1,457	428,250	53,118	4,019,133
Wappapello Reservoir	44,396	2,179,000	171	125,000
Lower Arkansas River (South Bank)	2	400	--	--
Tensas Basin (Red River Backwater)	27	3,100	--	–
Yazoo Basin (Backwater)	185	55,500	19,583	405,400
Yazoo Basin (Headwater):				
Arkabutla Lake	36,031	1,895,300	16,264	301,300
Enid Lake	43,437	2,486,700	225	15,300
Grenada Lake	84,410	3,924,900	2,416	85,000
Sardis Lake	98,063	2,023,300	306	17,000
Greenwood Protection Works	12	8,000	1,414	354,300
Yazoo City Protection Works	192	80,400	169	37,900
Whittington Auxiliary Channel	--	–	11,996	879,500
Main Stem	4,353	288,900	8,379	1,443,400
Tributaries	15,795	3,327,100	10,290	1,292,500
Big Sunflower River, etc.	20	2,600	–	–
Totals	340,579	$17,815,373	608,846	$22,097,324

* Includes cost of relocations.

Table 3 gives similar information for acquisition by local agencies, separately, for costs reimbursed by the Federal Government and for costs not reimbursed. The figures are for the project adopted by the 1928 act, as amended, through 30 June 1972.

Table 3

Total Acquisitions by Local Cooperating Agencies Through 30 Jun 1972

Project Feature	*Fee*		*Easement*	
	Acres	*Cost*	*Acres*	*Cost*
Local Agency Acquisition—Cost Reimbursable				
Atchafalaya Basin		$	25,038	$ 2,030,630
Lower White River			580	68,000
Lower Arkansas River (North Bank)			3,783	431,300
Lower Arkansas River (South Bank)	666	32,100	9,589	755,500
South Bank Red River			1,102	485,482
Mississippi River Levees			5,287	4,267,736*
St. Francis Basin			29,757	5,668,758
Tensas Basin:				
Boeuf and Tensas Rivers, etc.	–	–	59,726	2,624,300
Red River Backwater Area			7,507	1,044,300
Yazoo Basin (Backwater)			4,858	534,300
Yazoo Basin Headwater:				
Big Sunflower River, etc.	–	–	31,809	1,862,900
Totals	666	$32,100	179,036	$19,773,206
Local Agency Acquisition—Cost Not Reimbursed				
Atchafalaya Basin	6		174	
Mississippi River Levees			106,372	
Red River			840	
St. Francis Basin			8,753	
Lower White River			450	
Reelfoot Lake			2,100	
Memphis Harbor	660		57	
Wolf River and Tributaries			1,300	
West Tennessee Tributaries			15,285	
Cache River-Bayou DeView			578	
Greenville Harbor	1,889			
Vicksburg Harbor	1,115			
Harrisonburg to Little River New Levee			192	
Marshall Bend Levee Extension			98	
Totals	3,670		136,199**	

* Includes cost of relocations.

** Additional rights-of-way required; does not include rights-of-way owned by local agencies prior to project authorization.

Local Cooperating Agencies

As has been brought out in Chapter II, the customary requirements of local cooperation for local channel improvement and levee projects are the a, b, c assurances specified in section 3 of the 1936 Flood Control Act—namely, provide lands, easements, and rights-of-way necessary for construction of the project; hold and save the United States free from damages due to the construction works; and maintain and operate after completion. Congress, recognizing that local conditions may warrant deviations from these requirements, has authorized projects in accordance with the recommendations of the Chief of Engineers, subject to the conditions of local cooperation set forth in his recommendations. Deviation may consist of requiring less of or requiring more than is covered by the a, b, c assurances. In calling for the furnishing of this local cooperation as a precedent to the expenditure of Federal funds, the project documents and congressional acts make reference variously to "States, political subdivisions thereof, or other responsible agencies," "States or levee districts," "local interests," "local agencies," and the like. A prerequisite is that the cooperating agency be legally competent.

Within the lower Mississippi Valley, compliance with the local cooperation requirements of project authorization has been mainly by levee or drainage districts, aided within the State of Louisiana by the Louisiana Department of Public Works. Assurances concerning projects other than for flood control and major drainage, such as harbor projects, have been furnished by cities, counties, or public bodies sponsored by them. With increasing emphasis placed on projects for recreation, designation of additional groups can be anticipated to fulfill the requirements for administration, operation, and maintenance of recreation facilities; to operate gated openings; and to perform other functions prescribed by the authorizing acts.

In his *Levee Districts and Levee Building in Mississippi,** Robert W. Harrison describes the creation, organization, and functions of levee districts in the period from 1879 to 1950. Most of the levee construction formerly performed by the levee districts has now been taken over by the Federal Government, and today the primary function of these districts is the maintenance of levees, both district and Federal, and the construction of drainage works necessary to protect the levees.

There are many levee and drainage districts within the lower Mississippi Valley that are empowered by State law to furnish assurances of local cooperation. They are a form of special-improvement district, created by the governments of the respective States, generally by the State legislature in response to the desires of a specific area. In some instances, existing levee districts have developed by combination of earlier, smaller districts. Each district has its prescribed boundaries, established type of management, limitations on the amount of debt it may assume, powers of taxation and eminent domain, and other powers necessary for the conduct of business. Each district is managed by a board, whose members may be directly elected by popular vote or, in some instances, appointed by the Governor. The Louisiana Department of Public Works is an outgrowth of the Board of State Engineers, organized in 1871 expressly to provide central planning in the field of flood control in Louisiana. The Department inherited this function upon its organization in 1940. Although most major flood control work in Louisiana is now constructed by the Corps of Engineers, much of the work is instigated by the Department. Its policy is that the State must look after its own interests in this field and not delegate the responsibility to the Federal Government. Accordingly, the Department investigates, reports its findings, and urges its solutions on the Corps of Engineers and the Congress. In addition, the Department acts as engineering

* Published in October 1951 by the Mississippi Agriculture Experiment Station.

advisor to the levee districts and is required by law to make an annual inspection of all levee systems immediately after the high water season. Maintenance of flood control works is a responsibility of the levee districts, with which the Department works closely.

Many of the improvements now constructed or recommended are the direct result of requests and testimony by local interests before flood control committees of the Congress. In addition, local interests serve to keep citizens in their districts informed as to the need for water resource improvements, and to establish and regulate an organized program of flood relief and drainage. They maintain a needed liaison between Federal agencies and the people served by them.

CHAPTER V. PROJECT EXPERIENCE

Great Floods on the Lower Mississippi River

The Mississippi Valley is subject to frequent and severe floods. Major floods on the lower Mississippi generally result from large floods on the Ohio River augmented by contributions from other major tributaries of the lower Mississippi River. The flood season on the Mississippi River usually extends from the middle of December through July. Major floods on the Ohio River generally occur between the middle of January and the middle of April. Major floods from the upper Mississippi and Missouri Rivers occur between the middle of April and the last of July, and from the Arkansas, White, and Red Rivers between the first of April and the end of June.

The first flood on the Mississippi River of which there is any record was observed by members of DeSoto's expedition, probably in the vicinity of the mouth of the Arkansas River, in 1543. Writings of other explorers and early settlers indicate frequent flooding in the Alluvial Valley. Fragmentary records indicate that great floods occurred in 1782, 1785, 1796, 1809, 1815, 1823, 1844, 1849, 1858, 1862, 1867, and 1882. In recent years, major floods were recorded in 1903, 1912, 1913, 1916, 1922, 1927, 1937, 1945, 1950, and 1961. The largest flood at Cairo occurred in 1937, with a discharge of 2,002,000 c.f.s. The largest flood at Arkansas City occurred in 1927 with an estimated confined discharge of 2,615,000 c.f.s. The largest flood at the latitude of Red River Landing occurred in 1927, with an estimated confined discharge of 2,345,000 c.f.s.

The 1913 flood on the lower Mississippi River was primarily the result of a major flood from the Ohio River. The storm causing that flood was large and torrential, centering over the Ohio River Basin between 23 and 27 March. For the Ohio River drainage area, the average precipitation was 4.58 inches; the lowest was 0.73 inch for the Missouri River Basin; and the average for the lower Mississippi was 2.42 inches. The flood of 1927, which exceeded all floods of previous record throughout the lower Mississippi Valley below the mouth of the Arkansas, was the result of a series of storms. Precipitation throughout the Mississippi watershed was more abundant than usual during the fall of 1926, and heavy rains continued from December 1926 to April 1927 throughout the central areas of the valley. The major storm of the flood was that of 12-16 April which occurred on a rising lower Mississippi River, already high from antecedent rainfall. For the period 8-22 April, the average precipitation over the lower Mississippi area was 7.47 inches. For the White River Basin, the average was 12.27 inches, and the lowest average was 2.74 inches for the upper Mississippi River.

The January to March 1937 flood is the highest of record on the Mississippi from Cairo to the mouth of the Arkansas, and it also produced the highest stage of record at Natchez. It resulted from a continuity of precipitation of relatively low intensity from late December 1936 to mid-January 1937 over the entire Ohio River drainage basin, climaxed by a 6-day period of excessive precipitation of relatively high intensity over an area adjacent to the Ohio River and the lower reaches of its lower tributaries. There were January floods on the St. Francis, White, Arkansas, Ouachita, Red, and Yazoo Rivers, the crests of which generally occurred before the crest on the Mississippi. The average amounts of precipitation over the Mississippi watershed ranged from a high of 14.75 inches over the lower Mississippi to a low of 1.24 inches for the Missouri Basin, with an average of 4.86 inches for the Mississippi Basin. The discharge at Cairo was over 2,000,000 c.f.s., less than 200,000 c.f.s. of which was contributed by the upper Mississippi. The maximum discharge was 2,159,000 c.f.s. at Arkansas City, and about 1,900,000 c.f.s. at the latitude of Angola. The 1937 flood imposed the first major test of the effectiveness

of new levees built to the 1928 grade and section, as well as of the partially completed program of cutoffs and corrective dredging. The test was successfully met as the flood was passed through the Alluvial Valley without a crevasse in the main-line levees. In addition, it made necessary the first operation of the Birds Point-New Madrid Floodway and of the Bonnet Carré Floodway.

Section 7 of the Flood Control Act of 1928 authorized the appropriation of $5,000,000 as an emergency fund, to be allotted by the Secretary of War on the recommendation of the Chief of Engineers in rescue work or in the repair or maintenance of any flood control work on any tributaries of the Mississippi River threatened or destroyed by flood, including the flood of 1927. Section 9 of the act of 15 June 1936 authorized the appropriation of $15,000,000 for the same purpose, to include any flood theretofore or thereafter occurring, and provided for allotment of the unexpended and unallotted balance in the reimbursement of levee districts or others for expenditures made for the construction, repair, or maintenance of any flood control work on any tributaries or outlets of the Mississippi River threatened, impaired, or destroyed by the flood of 1927 or subsequent flood. Section 9 also made provision for allotment of such balance in case of impairment, damage, or destruction by caving banks of such tributaries whether or not such caving took place during a flood stage. Finally, section 9 gave the Chief of Engineers discretionary authority to change the location of any such flood control work, if necessary to provide the contemplated protection. In section 204 of the Flood Control Act of 1950, under the item "Lower Mississippi River," an additional sum of $5,000,000 was authorized to be appropriated as an emergency fund for the purposes set forth in section 9 of the 1936 act. Under these authorizations, the sum of $14,900,300 has been appropriated and expended.

Flood-fight operations necessitated by the 1937 flood began in the Memphis District on 15 January with preparations to close railroad and highway openings in the flood protection system. Other work included strengthening and raising of levees, building mud boxes and bulkheads to increase the height of floodwalls, controlling sand boils and seepage by construction of sublevees, and repairing rainwash and wave wash. Personnel of the Districts functioned as advisors to local agencies, and made inspections of their maintenance work on flood control structures. In the Vicksburg District, topping of the east-bank levee was unnecessary because ample freeboard had been provided, but wave-wash repair was required. In the New Orleans District, the principal flood-fight operations consisted of topping the reaches of Mississippi River levee that had not been brought to 1928 grade and section, and providing wave-wash protection, particularly below the latitude of New Orleans. Gaps in the east and west Atchafalaya guide levees were closed, and low spots in the Atchafalaya River levees were topped. Efforts to breach the fuseplug levee of the Birds Point-New Madrid Floodway by trenching through the top of the levee were unsuccessful and it was necessary to resort to dynamiting. The artificial openings enlarged and effected a small lowering of the stage at Cairo. The Bonnet Carré Floodway was placed in operation for the first time on 30 January 1937 and, at the time of the crest stage at New Orleans, about one-seventh of the total flow of the Mississippi River was diverted through the floodway and into Lake Pontchartrain.

A series of heavy rains from the middle of February to 7 March 1945 over most of the Ohio River Basin, aided to some extent by snowmelt in the northern section, produced the major flood of 1945. In the upper Mississippi and Missouri River Basins, above-normal temperatures caused an early spring melt of snow and ice accumulations. Rapid thawing and above-normal precipitation caused heavy runoff. The flood crests from the upper Mississippi and Ohio Rivers coincided to produce a crest discharge of 1,470,000 c.f.s. below Cairo. Exceptionally heavy rains over the lower Mississippi Basin, averaging more than 10 inches during March, preceded by heavy rains in the latter part of February, kept the Arkansas, lower White, and Ouachita Rivers above flood stage throughout March. Heavy rains at the

end of March produced record stages at many points in April. The lowering effect of the then well-developed system of cutoffs prevented higher stages from occurring. The lower Mississippi and Atchafalaya rose gradually during March as the floodwaters of the Ohio, Missouri, and upper Mississippi moved down. A flood of record proportions occurred on the Red River. Excessive flows from tributaries in the lower Mississippi Basin, together with the rise coming down late in March and early in April, produced stages at the latitude of Red River Landing somewhat in excess of those in 1937. The average precipitation over the Mississippi watershed was 4.99 inches during the period of 20 February to 31 March; the maximum amount was 16.40 inches over the White River Basin; and the Ohio and lower Mississippi Rivers had averages of 10.11 and 11.40 inches, respectively. The peak discharge was 1,900,000 c.f.s. at Arkansas City, with a like amount for the peak at Red River Landing. On 20 March, a stage of 52 feet was indicated for Red River Landing, which would result in a total flow greater than 1,911,000 c.f.s. at that latitude, and a stage of 20 feet or more was indicated for New Orleans. It was thus evident that Bonnet Carré would again have to be operated, and its opening was started on 23 March. On 2 April, flood routings, supplemented by estimates of flow from ungaged areas, indicated that a stage between 58 and 59 feet at Red River Landing was possible. If a stage of that magnitude had developed, it would have been necessary to operate the Morganza Floodway. It had been reported in 1944 that the Atchafalaya, Morganza, and West Atchafalaya Floodways could be used if required to pass great floods. Extensive preparations were immediately started to get the Morganza Floodway in condition to be operated. Numerous gaps had to be closed, towns protected, and levees built up to grades high enough to keep them from overtopping. Preparations were made to crevasse the levee at the head of the floodway. Two sections of this levee were armored with articulated concrete mattress with the object of controlling the width of the crevasse. On 4 April, it was concluded that the earlier estimates of inflow were somewhat high, and the prediction for Red River Landing was lowered to 57 feet, a stage which it was thought could be handled without the operation of Morganza, although it was so near the critical point that a heavy rainfall on the area immediately above could change the prospects overnight. Fortunately, there was very little rainfall over the area during the ensuing 2 weeks that would affect the flood stage, and this circumstance, combined with the fact that the Atchafalaya took considerably more water than was expected, resulted in holding the crest stage at Red River Landing to 56.4 feet.

The severe limitations imposed by World War II affected nearly all phases of the 1945 flood fight. The emergency operations included preparatory work, consisting of items that had long been unfinished for various reasons; extensive closure operations that had to be completed on very short notice; and a great deal of routine flood fighting which included a number of serious emergencies. Army equipment was utilized to great advantage, and Army personnel and prisoner-of-war units rendered valuable assistance. Contractors' organizations familiar with the work and having local knowledge of the river were also utilized, together with their construction equipment. The local interests, comprised primarily of the various levee boards and cities involved, and secondarily of the local, county, and State governmental agencies, were responsible for furnishing security guards where needed, for furnishing patrolmen for inspections, and for performing emergency work on the levees within their capabilities.

The flood of January to March 1950 resulted from a protracted period of moderate to heavy precipitation over the Ohio River Basin and major tributaries of the lower Mississippi River. In January 1950, three to four times the normal rainfall covered a band 200 miles wide, extending from Memphis to Toledo, Ohio. In general, the January 1950 rainfall over the Ohio River Basin was second only to that of January 1937. Excessive precipitation continued throughout the first 3 weeks of February over

the Ohio River Basin and the lower Mississippi River. The Ohio River was above flood stage at its mouth from 6 January to 7 March, with maximum discharges of 1,220,000 c.f.s. on 20 January, and 1,300,000 c.f.s. on 13 February. The maximum discharge from the upper Mississippi and Missouri Rivers at Thebes, Illinois, was 377,000 c.f.s. on 17 January. The coincidence of the two peaks of the first rise was very close, which contributed considerably to the discharge on the lower Mississippi River. In February 1950, the Mississippi River stages in the Memphis District above Helena were the highest since 1937. The stage at Cairo was the third highest of record. However, agricultural losses in the upper river were low due to occurrence of the flood prior to the planting season. Excessive January precipitation over the tributaries of the lower Mississippi River added large volumes of water to the flood in the lower basin. The average amount of precipitation over the Mississippi watershed was 3.70 inches. The average amounts for the Ohio River, White River, and lower Mississippi drainage areas were 10.48, 10.78, and 11.02 inches, respectively. The maximum confined discharges were 1,624,000 c.f.s. at Cairo, 1,791,000 c.f.s. at Arkansas City, and 2,054,000 c.f.s. at the latitude of Red River Landing. This flood was the greatest of record below the latitude of New Orleans and in the Atchafalaya Basin from Krotz Springs to Six Mile Lake.

Flood-fight efforts in 1950 began early in January with mobilization and positioning of equipment and personnel at the site of the fuseplug levee of the Birds Point-New Madrid Floodway in the event that breaching of the levee should become necessary. Alerting notices of possible operation of the floodway were issued at various critical periods, and many floodway residents moved out of the area during the period of 11 to 18 January. Some of this evacuation was aided by the Red Cross and the National Guard. On 1 March, notices were released that flood forecasts indicated that operation of the floodway would not be necessary at that time. The levee system in the Memphis District withstood the flood satisfactorily except for heavy seepage in some reaches—generally of substandard levees—and except for wave wash at exposed locations and the occurrence of some scouring as a result of current velocities. In the Vicksburg District, the flood fight was concerned with corrective measures to eliminate threats to levees where breaks in revetments had developed, with topping out of low, incompleted levees, and with construction of loop levees around sections of levee threatened by bank caving. Rescue and relief operations of major proportions were required in the Red River backwater area where levees had been constructed to an interim grade. No patrolling or work could be done on the partially completed backwater levee which was overtopped by about a foot for some 20 miles. Practically all of Concordia Parish, south of the Ferriday-Jonesville Highway, was flooded except a few of the highest ridges. The major operations in the New Orleans District consisted in closing four gaps in the Atchafalaya Basin protection levees and closing the navigation gap at Bayou Teche on the west side of the Wax Lake Outlet channel. Below New Orleans, it was necessary to top out some reaches of levees to grade and section. It was again necessary to operate the Bonnet Carré Floodway. In the Atchafalaya Basin, 10 miles of the Butte LaRose levee were raised from 2 to 2-1/2 feet, and mud boxes were built at Morgan City and Berwick to prevent flooding of the outskirts of the urban areas.

Rains occurring over the Mississippi River and Ohio River Basins during May 1961 resulted in a Mississippi River crest stage of 54.45 feet on the Cairo gage on 16 May, with a corresponding maximum discharge of about 1,580,000 c.f.s. Stages on the Mississippi River in the Vicksburg District, which had been moderate for the latter part of 1960 and slightly below normal for January and February 1961, began to rise late in February and crested in May, reaching stages higher than had been experienced since 1950. They varied from 2 feet below flood stage at Arkansas City to 2 feet above flood stage at Vicksburg and Natchez. In the New Orleans District, the Red River Landing gage (flood stage 45.0 feet)

crested at 47.45 feet on 2 June, and on the following day, the Carrollton gage (flood stage 17.0 feet) crested at a stage of 16.35 feet, the highest since the major flood of 1950. The highest stages reached at Simmesport in the Atchafalaya River Basin and on the Red River at Alexandria were below the respective flood stages.

In addition to the system of cutoffs in the lower Mississippi River, started in 1932, other channel improvements have further shortened and stabilized the river. The bank protection works limiting the river meander and reducing solids carried by the river have made substantial changes in the stage-discharge relationship. The requirement for expensive setbacks of the levee system and the continuing sacrifice of protected lands have been essentially eliminated by this protection program.

Floods on Tributaries

Besides major floods experienced on the main stem, there have occurred floods on the tributaries too numerous to warrant individual description. Some have been caused by accumulated runoff from almost daily rainfall, and others have been due to intense localized storms of short duration. In the floods of 1931 and 1932 over the Yazoo Basin, the largest amount of rainfall occurred at Swan Lake on the Tallahatchie River where, in 3 months, it was almost equal to the total for a normal year. This storm series caused the most critical flood of record for the Tallahatchie and Yazoo Rivers, hence was selected as the design storm for the Yazoo Basin reservoirs. Flood-fight operations on the tributaries have included operations to control sand boils, improvised sack levees, landside and riverside berms, enlargement of substandard levees and construction of new levees, and levee setbacks in the vicinity of caving banks.

In the Ouachita Basin, it was necessary to close the gap in the Monroe city front, where 2,000 feet of floodwall through the business district remained to be constructed between Bry and Grammont Streets. Closure of this gap was accomplished by construction of a mud box on the pavement of South Grand Street, parallel to and 6 feet from the riverside curb and tying into the concrete floodwall at each end. Preceding construction of the mud box, a sack levee was constructed along the low reaches of this unleveed portion, and sack loops were also constructed to protect buildings outside the mud box as much as possible.

Stage Reductions Due to Reservoirs

In the Yazoo Basin, Sardis Reservoir was first in operation in 1940 and Grenada Reservoir, the last, was placed in operation in 1954. Stage reductions resulting from the reservoir operations and from other flood control works in the Yazoo Basin vary considerably from flood to flood, but to date they have averaged 4 feet on the Coldwater and Tallahatchie Rivers, and 3.5 feet at Greenwood. The value of reservoirs and other completed works in the Yazoo Basin is demonstrated by the reductions of flooding in the delta area, amounting to 531,000 acres in 1955; 485,000 acres in 1956; 448,000 acres in 1957; and 456,000 acres in 1958. However, the effects on flood stages in the main stem were of minor significance. In the St. Francis Basin, the operation of Wappapello Reservoir, completed in 1941, has lowered stages immediately below the dam as much as 9.0 feet (for the flood of 1943), and reductions of 2.0 to 3.5 feet at Fisk, about 15 miles below the dam.

Effects of Major Drainage

The reduction in stages from major drainage work varies considerably depending on the type of work and the storm. In the Big Sunflower Basin, the reduction averages from 1 to 3 feet. Equally as important as the stage reductions are the reductions in duration of overflow, which average from 25 to 50 percent. Major drainage work in the Boeuf and Tensas Rivers and Bayou Macon Basin was started in 1947, and the first phase had been largely completed by 1965. Reduction in this basin averages from 1 to 4 feet. The large increases in channel capacities afford important reductions in duration of overflow ranging from 50 to 75 percent. Most of this reduction takes place in late spring when it is especially beneficial.

Hurricanes

The proximity of the lower portion of the lower Mississippi Valley to the Gulf of Mexico exposes it to hurricanes. Although no official Weather Bureau meteorological records are available prior to 1893, early historical accounts tell of hurricanes that resulted in loss of life and property damage. There are records of the occurrence since 1893 of 18 severe hurricanes that have been accompanied by damaging hurricane tides.

Of recent occurrence was Hurricane Betsy which struck the Louisiana coast just west of Grand Isle and passed 35 miles southwest of New Orleans on 9 September 1965, causing widespread damage from flooding as well as from high winds. Flooding in the city of New Orleans resulted from levee crevasses and overtoppings along the Industrial Canal, and from flooding in parts of the area between New Orleans and Venice due to overtopping of the main-line Mississippi River levees by wind-induced tides. Grand Isle recorded the lowest barometric pressure (28.00 inches) and the highest winds (160 miles per hour). At New Orleans, a barometric pressure of 28.75 inches and winds of 125 miles per hour were recorded. The eye of the hurricane was 40 miles wide with hurricane winds extending out 90 miles and gale-force winds 250 miles in all directions. The tidal surge accompanying the hurricane ranged from about 8 feet, mean sea level, at Grand Isle to more than 16 feet, mean sea level, east of the Mississippi River below New Orleans. Severe damages to both main-line and back protection levees occurred from New Orleans to Venice (see figure 74). Damages to the main-line levees were caused by vessels and debris striking the embankments and by overtopping from the tidal surge in the Mississippi River. Damages to the back protection levees were caused mostly from overtopping by wind-driven waters crossing the marshes. The total damages within the New Orleans District from all causes attributed to Hurricane Betsy were estimated at $371,960,000.

Of more recent occurrence was Hurricane Camille, which struck the State of Mississippi coast just west of Pass Christian on 17 August 1969, resulting in damages from New Orleans eastward to the Mississippi-Alabama State line. This was the most intense hurricane of record to strike the Gulf coast area or the United States mainland. A low barometric reading of 26.85 inches was recorded at Bay St. Louis, and wind velocities of 160 miles per hour with gusts of 180 miles per hour were experienced at White Sand, Mississippi. The tidal surge which accompanied Hurricane Camille produced high stages in the New Orleans area, and severe damages occurred to both main-line and back protection levees from just below New Orleans to Venice. Damage in Plaquemines Parish from Port Sulphur southward was comparable to that caused by Hurricane Betsy, making it the second time within four years that the area had been devastated by hurricanes.

Figure 74. Typical scene of damage to levees on lower Mississippi River by Hurricane Betsy

In recent years, Congress has authorized, as Flood Control, General projects and subject to requirements of local cooperation, the construction of improvements for prevention of hurricane tidal damages and loss of life.

Benefits from Upstream Reservoirs

Detention of floodwaters in reservoirs on tributaries of the Mississippi obviously reduces main-stem flood stages. In planning the initial reservoirs, it became the general practice to utilize estimates of the benefits of such reductions in the economic justification of the reservoirs. The methods initially employed were known to be approximate. A study of improved procedures, entitled "Mississippi River Reservoir Benefit Study," was completed by the Office of the President, Mississippi River Commission in 1961, and revised in 1963. This study reviewed the effects of tributary reservoirs on flood stages and damages along the main stem of the Mississippi River below St. Louis, Missouri. It included estimation of the reductions in flood discharges and stages at key points along the Mississippi River between St. Louis and the mouth, corresponding to floods of various magnitudes, attributable to reservoirs completed or under construction in 1955 (group E); to those expected to be completed by 1970 if fund appropriations were made pursuant to the 6-year program of 1955 (group N); and to all reservoirs authorized in 1955 and additional reservoirs then definitely planned (group D). The estimates were based upon analyses of floods of record, with appropriate generalization and some extrapolations. The study also included calculation of the amounts of dependable reductions, by specified reservoir groups, of hypothetical floods in the category of the project flood; estimation of the effects of these reservoir groups in increasing

critical low flows in the Mississippi River from St. Louis to the mouth, with resulting benefits to navigation, water supply, and pollution abatement; and distribution of Mississippi River flood reduction effects, low flow augmentation effects, and related monetary benefits from reservoirs to major tributary basins and subdivisions of them.

Flood discharge reductions due to reservoirs were considered in two categories: (1) reduction of the project design flood, yielding a one-time benefit due to saving in cost of construction of flood control works that would otherwise be required to contain the unmodified flood, and (2) reduction of nonovertopping floods, effecting annual flood control benefits through reduction of crop damage in unprotected areas and lessening of damages to land improvements, as well as savings in flood-fighting costs. The unprotected areas contain improved and unimproved lands, farm improvements, and utilities.

Except for the 1945, 1950, and 1961 floods, the major floods on the main stem previously described occurred before construction of upstream reservoirs had advanced sufficiently to permit demonstration of the capabilities of the reservoir system in reducing floodflows on the lower river.

Regulation of the upstream storage reservoirs also makes possible the augmentation of main-stem streamflows at times of low water on the lower Mississippi River. The study recognized that the magnitudes of such augmentation are subject to depletion due to withdrawals for agricultural purposes in the Missouri Basin, which would be substantially larger in the year 2020 than in 1970. However, the study conclusion was that there was little likelihood that any benefits to irrigation would be creditable to reservoir releases, even if irrigation development should take place to the maximum extent then considered probable. This was due to the belief that there would be enough ground water to supply the entire demand in most areas, and that use of ground water would be more convenient and economical. It was thought at that time that, in any event, all the foreseeable need for irrigation purposes could be supplied by direct withdrawals from the prevailing unregulated flows of the Mississippi River without serious detriment. Reconsideration of this conclusion in 1969 and 1970 has modified this view; local interests now foresee increased demands for crop irrigation and advocate timely supplementation of streamflows by reservoir releases.

Navigation would likewise benefit from flow augmentation during periods of low flow, resulting in reduction in channel maintenance dredging where necessary to assure a 9-foot channel in the Memphis and Vicksburg Districts. However, reservation of upstream storage for purposes of hydroelectric generation has so far had a higher priority that prevented such releases.

In considering whether the reservoir system should be operated to alleviate losses due to polluted or inadequate domestic water supplies, or to reduce expenses for alleviation of those conditions by water treatment or by development of new water sources, the study concluded that the then known difficulties could be remedied at small cost, hence were not sufficient to warrant ascribing tangible benefits to reservoirs. Over the whole river, from St. Louis to the mouth, even without reservoir contribution to low waterflow, the actual potential economic damage then estimated was very small. Even without such augmentation, there was thought to be ample water for the foreseeable future, for such nonconsumptive uses as steam generator condenser cooling. Despite some potential benefit from the use of reservoir releases for pollution abatement, it was not then thought that it was sufficient to warrant assignment of a monetary value. Growing nationwide concern about the country's water resources in recent years has influenced this thinking and resulted in higher evaluation of upstream storage.

Levee Crevasses

It has been reported that in the great flood of 1882, a total of 284 crevasses, with a combined length of 56.1 miles, occurred in the main-stem levee lines. Similar breaks took place in succeeding floods for many years. However, the number decreased as levee grades were increased and sections were enlarged. During the 1927 flood, the greatest of record, the main-stem levee lines crevassed at only 13 places. During succeeding floods, no levees complete to grade and section have crevassed. However, crevasses of substandard levees on tributaries have been experienced. For example, heavy rains throughout the St. Francis River Valley in March 1935 produced a stage of 21 feet on the Fisk (Missouri) gage, with a sustained rise in sight, and in consequence there were numerous breaks in the east and west levees between 15 and 23 March. Again, during the 1950 flood, high stages on the St. Francis River caused the substandard nonproject levee system to crevasse in five places. Neither the height nor duration of the flood was of sufficient magnitude to endanger the project levee system. Troubles of a serious nature were confined to those areas where substandard levees existed.

By coincidence during the course of the potamology investigations, a major failure occurred at Free Nigger Point, located on the right bank of the Mississippi River a few miles above Baton Rouge (see figures 30 and 31). In a matter of only a few hours, more than four million cubic yards of bank material slid into the river, moving and destroying a considerable length of levee. The river was on a falling stage, just past the crest of the 1950 flood, but still well overbank. The flow slide extended so far laterally into the bank that it crevassed the main-line levee located 800 feet from the bank, starting overbank flooding behind the levee line. A major emergency construction effort by forces of the New Orleans District succeeded in building a setback in a matter of hours, thereby averting a major catastrophe. An unusual feature of this slide was that it occurred on the inside or convex bank of the river rather than on the outside or concave bank where such caving usually occurs. This levee break was not considered to be a normal levee crevasse caused by flood stresses or overtopping.

Reservoir Spillway Utilization

Spillway structures were provided in each of the five reservoirs as "safety valves" to assure that overtopping of the dams would not occur in case unusual events should cause the reservoir storage capacity below the spillway crest elevation to be exceeded. Two of these spillways have discharged floodwaters: one (Wappapello), within 4 years following completion of the dam; and one (Arkabutla), 12 years after completion of the dam.

Design of Wappapello Reservoir for flood retardation envisioned that the regulated outflow would not exceed the capacity of the project leveed floodway below the dam. The floodway levees were designed to have a 3-foot freeboard above a flow line computed for a 10,000-c.f.s. outflow from the reservoir, augmented by runoff of 12 inches in 30 days from the area below the dam. Upon completion of the dam and before the locally constructed substandard levees downstream had been enlarged, an interim plan of regulation was adopted which required a reduction of outflow below the 10,000 c.f.s. established by the design. This procedure resulted in preserving the integrity of the substandard levees until March 1945, when the runoff from a series of intense storms brought the pool to a maximum elevation 4.3 feet above the crest of the uncontrolled spillway. The resulting reservoir outflow reached a maximum of 22,000 c.f.s. Although flows of such magnitude were of frequent occurrence before the dam was

constructed (a maximum of 85,000 c.f.s. having been experienced in August 1915), excessive flooding of the reservoir area with disruption of traffic on a major highway led to the decision to follow the design plan of regulation for future floods without deviation.

Rainfall over the Arkabutla drainage area averaged 8.1 inches during April and 13.6 inches in May of 1953. As the flood control capacity was sufficient for storage of only 9.3 inches of runoff from the drainage area, the reservoir stage reached following this storm exceeded the spillway crest elevation by 3.4 feet. For the period of maximum reservoir stage, the gates of the outlet structure were closed and the unregulated spillway discharge was then estimated to be 7,100 c.f.s. The planned maximum regulated outflow is 5,000 c.f.s. Calculations made at the time of the reservoir design gave an estimated frequency of spillway operation of once in 23 years.

Operation of Birds Point-New Madrid Floodway

In 1937, construction of drainage ditches and appurtenant structures necessary to carry the drainage intercepted by the Birds Point-New Madrid Floodway setback levee had been completed for about 5-1/2 years. Construction of the setback levee was complete except for a short gap at the Missouri Pacific Railroad crossing. The fuseplug sections of riverfront levee had not been degraded to project grade.

The 1937 flood overtopped, crevassed, and scoured the riverfront levee in many places and inundated the entire floodway which, at crest stage, handled about one-fourth of the entire flow of the river. The flow of water into the floodway was facilitated by three crevasse groups in the 11-mile upper fuseplug section, four in the central reach of the riverfront levee, and one in the lower reach. Outflow from the floodway developed one large crevasse and many smaller crevasses and scours in the lower reach, as well as numerous crevasses in the lower fuseplug section.

The gap at the Missouri Pacific Railroad crossing was filled with sandbags during the January-February 1937 flood. After passage of this flood, all the openings in the riverfront levee except those in the lower reach and in the lower fuseplug section, were closed by interim levees under repair contracts or by emergency work of sufficient magnitude to prevent headwater flooding from the rise of May 1937. The break near river mile 49 admitted some headwater to the extreme southern part of the floodway and increased the backwater stage slightly. Later in the construction season, restoration of the levee to previous grade and section at all crevasses and scours above the lower fuseplug section was accomplished by contract forces. In spite of heavy damage to buildings in the floodway by the flood, the inhabitants moved back and resumed farming.

During the onset of the 1945 flood, preparations were begun for a second use of the Birds Point-New Madrid Floodway, but this did not become necessary, nor has the floodway been used in later floods.

Operation of Bonnet Carré Floodway

By late 1936, construction had been completed of the Bonnet Carré spillway structure and of all floodway items, including highway and railroad crossings and degrading of the Mississippi River levee across the entrance to the spillway approach channel. The structure was first placed in operation during the 1937 flood by gradually opening the spillway bays, beginning on 30 January and continuing until 18 February, by which time 285 of the 350 bays were in operation. With these openings, the maximum discharge recorded was 211,000 c.f.s. The designed maximum discharge with all bays in operation is

250,000 c.f.s. The bays were gradually closed during the period from 7 to 16 March. The date of opening of the bays was planned to prevent the Carrollton gage from exceeding 20 feet. The closing schedule attempted to diminish the daily weir discharge by an amount approximately equal to the decrease in riverflow, thereby holding the Carrollton gage stationary.

During the operation of the spillway, a motorboat was operated continuously above the weir forebay as a "drift patrol," the function of which was to prevent drift from being drawn against the weir and to remove debris that accumulated against the structure. Continuous patrols were maintained to read the 150 gages established in the river forebay, the floodway, and Lake Pontchartrain and to observe and report on conditions of guide levees, current, and drift. Observations of velocity, path of flow, and discharge were made continuously during spillway operation, and scour and silting studies were made throughout the floodway following the weir closure. During the flood period more than 1,000 men were directly employed on the floodway in operation, construction, patrol, and observation activities. No damage to the structure was noted, although considerable localized scour and general siltation occurred. The most severe scour occurred in the lower end of the floodway, on the left side between Lake Pontchartrain and the Illinois Central Railroad bridge. Sand and silt, estimated to have a total volume of 7,200,000 cubic yards, accumulated in the upper end of the floodway between the Mississippi River and the Airline Highway (U. S. 61). From the river to the Yazoo and Mississippi Valley Railroad bridge, fill occurred across the entire floodway but was heaviest in the central area. From the Yazoo and Mississippi Valley Railroad bridge to the Airline Highway, the principal filling was on the right side.

Following the initial operation of the floodway, maintenance, repair, and improvement of flow conditions were undertaken. Scour areas were repaired and sand and silt deposits were leveled; the floodway above the Airline Highway was cleared of brush and prepared for pasture with the intention of preventing the recurrence of deteriorating growth; timbered areas within the floodway were cleared of underbrush; and a channel, 2,650 feet long, requiring excavation of 951,000 cubic yards and designed to effect better distribution of flow near the lower end of the floodway, was dredged. The material dredged was deposited in a spoil-bank dike riverward of the Illinois Central Railroad crossing to prevent scour between the upper guide levee borrow pit and Lake Pontchartrain. It was anticipated that these measures would result in more efficient operation of the floodway, with lowered flow-line elevations and more uniform distribution of flow in the floodway.

The Bonnet Carré Floodway was opened again on 23 March 1945. At that time, the stage at the Carrollton gage was at 18.6 feet, and stages in excess of 20 feet were predicted. The discharge was restricted for several days so that cattle could be moved out of the floodway area. Thereafter, the bays were opened as required until 4 April, when all were opened. The crest stage of 19.8 feet occurred on 1 May. The floodway discharge at the Airline Highway bridge was 245,000 c.f.s. on 5 April and 318,000 c.f.s. on 17 April, with an average discharge of 270,800 c.f.s. for the period of full operation. It was estimated that the Carrollton gage would have reached 22.5 feet if the floodway had not been operated. Closure proceeded between 10 and 18 May as required to maintain the Carrollton gage below 19 feet.

The 1950 operation of the Bonnet Carré Floodway (see figures 75 and 76) began on 10 February after stages in excess of 20 feet on the Carrollton gage had been predicted. The river crested on 10 February at 19.98 feet. Bays were opened as required until 23 February, when all were opened. The maximum discharge measured at the Airline Highway Bridge was 222,800 c.f.s. on 4 March, with the Carrollton gage reading 19.5 feet on 5 March. Discharges averaged 156,000 c.f.s. for the period of full operation. It was estimated that the Carrollton gage would have reached 21.5 feet if the floodway

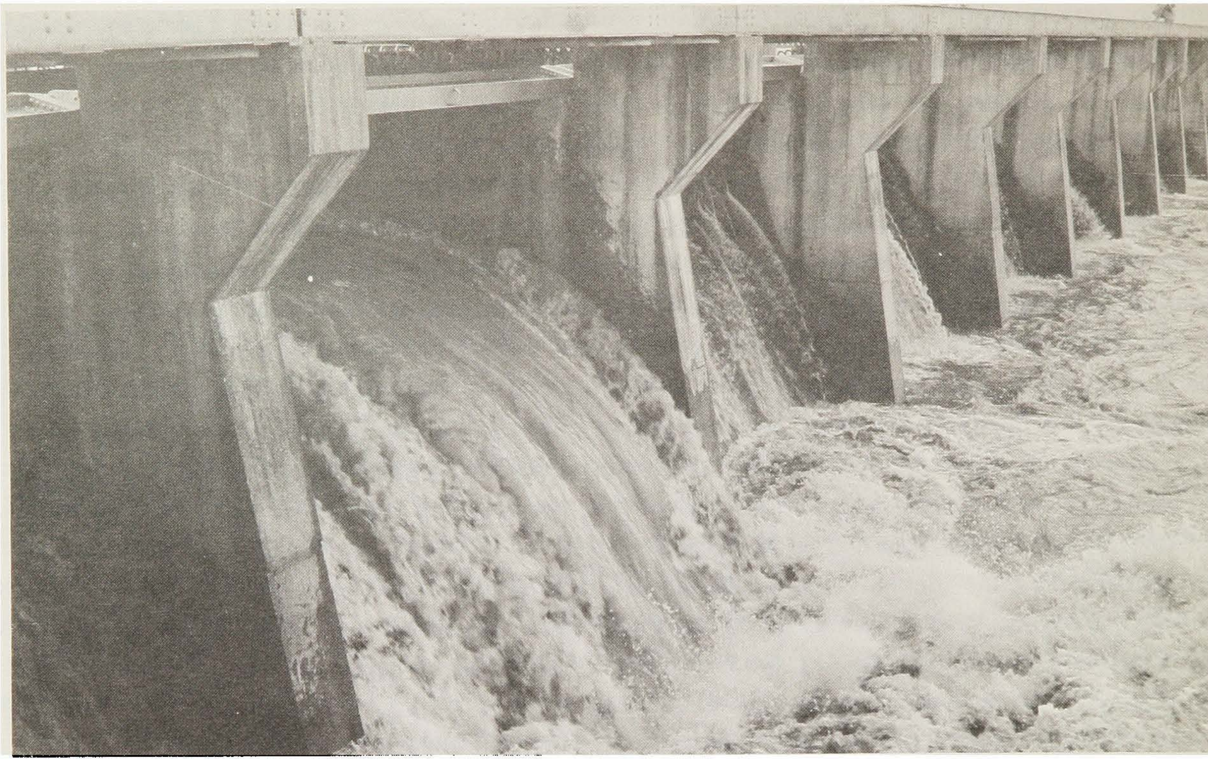


Figure 75. Operation of Bonnet Carré Spillway in 1950

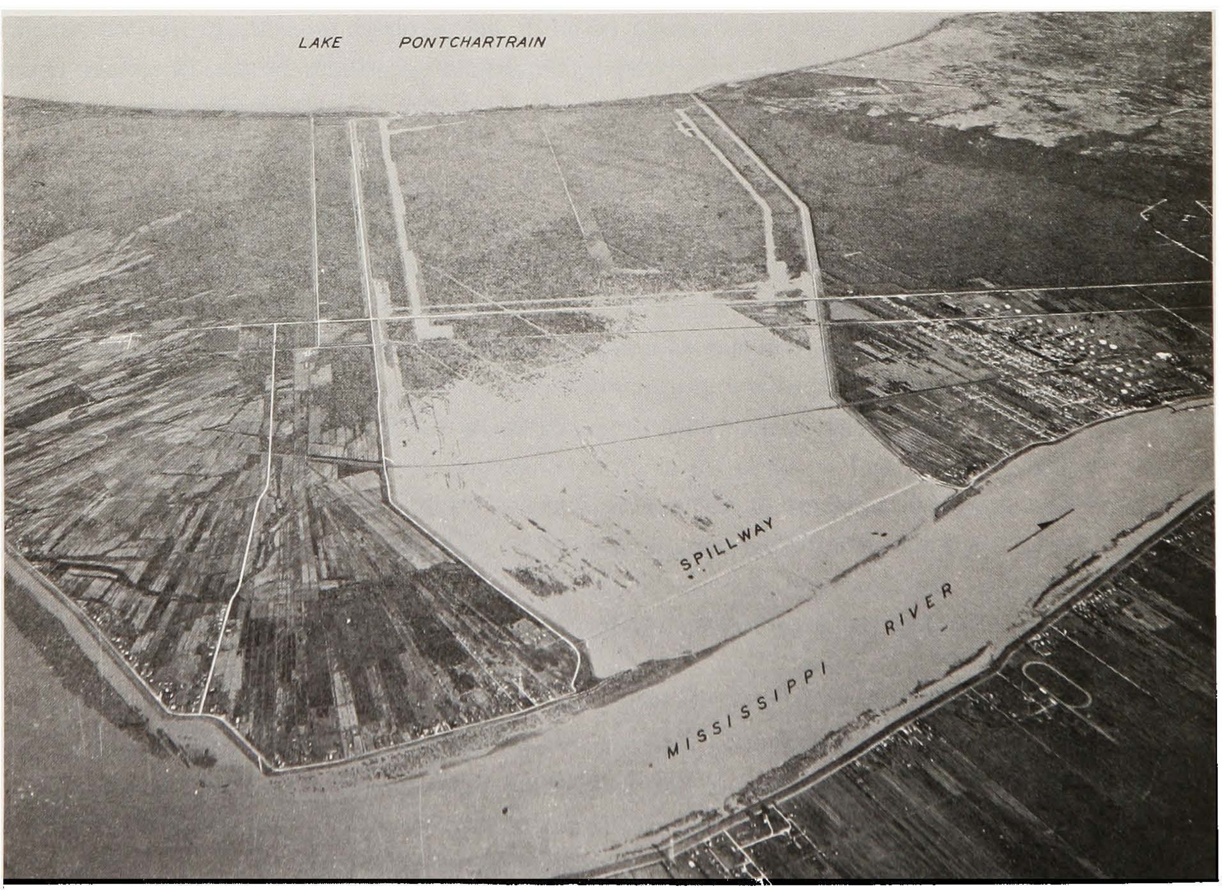


Figure 76. Aerial view of Bonnet Carré Floodway in operation

had not been opened. Between 11 and 19 March, closure was effected as required to maintain the gage below 19 feet. In view of the predicted need for full capacity operation, entrance conditions were improved by dredging 1,485,000 cubic yards from the forebay during the period from 24 February to 26 March.

Considerable apprehension had been manifested concerning the possible effect of floodway operation on the condition of oyster reefs in Lake Pontchartrain due to the introduction of large amounts of fresh water. A survey by the U. S. Fish and Wildlife Service was commenced following the announcement on 9 February of the plan to operate the floodway. The survey, concerned with the condition of oyster reefs and water quality, showed that the water in much of the region was already too fresh for normal growth of oysters. It was concluded that the low level of salinity over most of the lake area did represent potential danger to the oyster population, but that recovery of the lake water from the low-salinity condition is rapid when prevailing winds are southerly and tributaries cease flooding.

Operation of Old River Low-Sill Control Structure

Trial operation of the low-sill control structure was conducted during the summer of 1961 to obtain data on the hydraulic capacity of the structure; to check the adequacy of channel-scour protection; and to train operating personnel. After nearly 3 months of operation at medium river stages, a scour hole developed on the right side of the outlet channel immediately downstream from the end of the riprap protection. The scour extended to elevation 40 feet below mean sea level, which was a depth of 30 feet below the original channel invert. Early in 1962 the channel section was restored by placement of 4,000 tons of riprap and crushed stone in the scour hole. Trial operations were resumed in February and continued through August 1962, when it was found that the scour hole had reopened and enlarged to a maximum depth of 90 feet below mean sea level. This depth shoaled to about 60 or 70 feet below mean sea level as the discharge was reduced by closure of the gates. During December 1962 the riprap paving was extended by placement of 59,000 tons of riprap and crushed stone. Trial operations were resumed in March 1963 while the structure discharge was increased to facilitate closure of the Old River channel. Closure was made on 12 July 1963, after which time all flow from the Mississippi to the Atchafalaya passed through the outlet channel into Red River. Between the closure date and April 1964, flow ranged from 17,000 to 308,000 c.f.s., and no further scour occurred. However, when the spring rise began, progressive scour was discovered in the channel downstream from the end of the extended riprap paving. Settlement of riprap protection only 200 to 400 feet from the structure caused concern. Although various gate manipulations were employed to reduce current attack in the critical areas, the large downstream scour area continued to deepen and the hole reached a maximum depth of nearly 140 feet below mean sea level. When the discharge dropped off, shoaling reduced the maximum depth to about 100 feet below mean sea level. Repairs consisting of extension of the riprap protection on the bank slopes and placement of articulated concrete mattress were completed in December 1964. Repairs are required periodically to maintain the design channel section and to control bank caving, the scope of necessary work being directly related to the duration of high river stages.

In contrast to the difficulties experienced with the outlet channel, the revetted inlet channel has been relatively stable. However, in April 1964, 20 barges tied to the Mississippi River bank about 20 miles upstream from the low-sill structure broke their moorings and drifted down to the structure. Eight barges were drawn by the current into the forebay channel, colliding with the structure. Except for bay 3, the gates were closed within a few hours. The gate in bay 3 could not be closed because the opening

was obstructed by one of the barges, which ultimately passed through the bay and sank in the outflow channel. Aside from slight spalling of the concrete, the low-sill structure sustained no apparent damage. However, operation of the structure as planned was impossible for nearly 3 months, and as a result, record low stages occurred at points in the Atchafalaya Basin.

Occurrence of this accident after the low-sill structure had been fully operative for less than 10 months, followed by a second accident involving three barges in December 1965, gave rise to concern over the possibility of repetition of similar accidents, particularly in view of the serious consequences should it become necessary to close the gates during a major flood. Accordingly, study of means of protecting the structure against the threat of runaway barges, especially during high river stages, led to installation of a barge barrier. The barrier comprised five barges, each 235 feet long, lashed end to end and held in position by concrete anchors on the channel bottom and on the bank. Large amounts of drift carried by the flow to the low-sill intake were entrapped by the barrier. Removal of the material as it accumulated became a major problem, and late in 1967, the land anchor chain was broken on two occasions. Early in 1968, the barge barrier was removed. Consideration of alternative means of protecting the structure from damage by tows or barges drawn into the inflow channel is continuing. In the meantime, a picket boat has been assigned to patrol the Mississippi River immediately upstream of the structure and the structure forebay when the Mississippi is above elevation 15 feet, mean sea level, on the Red River Landing gage. In addition, a navigation regulation has been adopted that prohibits the anchoring of tows in the reach of river extending for 25-1/2 miles above the structure.

In the spring of 1964, when the river stage was above elevation 44 feet, mean sea level, vibration of the low-sill structure was detected. To ascertain the significance of these motions, particularly in relation to safety of the structure, a test program was formulated. Under the program, measurements of the vibrations were to be made when river stages were between 40 and 50 feet. Measurements began in March 1965 when river stages were slightly over 39 feet. Further measurements were made in April 1965 when stages were between 46.9 and 47.8 feet. Various gate openings were tried in each instance. Although observations thus far indicate a tendency for vibrations to increase with higher stages and greater differential heads, vibrations were at low levels and appeared to have no structural significance. Further measurements are scheduled to be made when river stages approach or exceed 50 feet, mean sea level.

Prototype Observations

For several years, the performances of major structures constructed under the project authorizations have been observed and compared with performances predicted in their design. This procedure insures continuing structural integrity and operational adequacy, and yields data that can be used in the design of future works. Five flood control dams, Morganza and Old River control structures, Old River lock, the larger drainage structures, and floodwalls have been instrumented for this purpose.

The soil mechanics and structural aspects include measuring the rebound of foundations during excavation, measuring the settlement and movement of the structures during and after construction, and observing the performance of relief well and drainage systems, adequacy of slope protection, and the overall performance of the structure.

The engineering measurement devices are installed in advance and during construction of the project, and are observed during and after construction. Data yielded by these observations are analyzed and form the bases of reports summarizing the findings. At intervals thereafter, supplements to the reports

are prepared to incorporate analyses made after preparation of the basic reports.

The prototype analyses program has emphasized the importance of a thorough geologic and soil mechanics investigation during the planning stage of a project to insure a safe embankment and foundation design. It has shown that it is possible to predict with some accuracy the amount of foundation rebound and settlement that will occur for structures on earth foundations. It has confirmed that seepage control measures are necessary for structures of the type observed, that such installations must be checked frequently after construction to determine their adequacy, and that proper maintenance is important.

CHAPTER VI. OPERATION AND MAINTENANCE OF PROJECT FEATURES

Levees

In meeting the maintenance responsibilities imposed by the 1928 act, as amended, the various levee districts have carried out annual programs, with their own forces, that have included cutting grass, weeds, and bushes on levees; filling holes and restoring rainwashed areas; clearing channels; correcting minor drainage problems; and seeding and sodding. With gravel furnished by the Federal Government, they have built all-weather roads on levee crowns. Other maintenance operations have included spraying of levees and ditches with chemicals to control noxious and unwanted growth, such as Johnson grass and willows. Work by the Federal Government has included restoration of eroded portions of existing levees, and restoration of damaged wave wash and foreshore protection.

The quality of maintenance performance varies with each local sponsor, ranging from excellent in some districts to scarcely more than satisfactory in others, depending to a considerable extent upon the availability of funds. In general, the levees are maintained somewhat better than the channel systems. This may be explained by the fact that, at the time of construction and reconstruction of the levees beginning in 1928, the levee system previously existing had been in operation and under maintenance for many years. The levee districts were well organized and provided a reasonable degree of maintenance in order for the levees to protect the adjoining lands from the frequent high water for which they were designed. The levee districts were thus prepared to take over and carry on the maintenance requirements of the project. Hence, the present high degree of maintenance performance results from the fact that these requirements have been in effect for 42 years, during which time maintenance activities have gradually increased year by year in response to the demands of a growing economy for more adequate protection from floods.

Navigation Channels

Currently, the 9- by 300-foot Mississippi River navigation channel is being maintained by seasonal dredging of crossings and removal of snags, as required. Preparation of plans for dredging take into consideration the results of weekly channel patrols, made during the low water season, and periodic channel patrols, made during the high water season. This maintenance function is accomplished by dustpan dredges. The number of crossings dredged or redredged, as well as the amount of dredging required to maintain a navigation channel in any low water season, depends largely upon the duration of the low water season and the frequency of stage fluctuations during the low water season. There are some 200 river crossings between Cairo and Baton Rouge. In recent years, there was an average of about 42 crossings dredged or redredged during a low water season. The average quantity of maintenance dredging, annually, during the past several years has been 36 million cubic yards. Review of long-term records of maintenance dredging, crossing depths, and channel patrols shows that the channel improvement program has reduced the total number of crossings usually dredged. It is concluded that, upon completion of the channel improvement and stabilization programs, a dependable year-round 12-foot navigation channel can be obtained and maintained.

Although the 1928 act required no local cooperation or contribution to navigation features of the adopted project, harbor improvements incorporated as project features by subsequent acts have been

subject to requirements of local cooperation similar to those of other Federal harbor improvement projects. Included is maintenance of the completed works except for maintenance of harbor and approach channels, which is a Federal responsibility. This work has usually been performed by cutterhead dredges. For the past several years, the total quantity involved in this operation has varied from 1,500,000 to 2,000,000 cubic yards annually.

Supplementing the prescribed channel patrols, the Mississippi River Commission maintains bulletin boards showing daily gage readings at regular gages, and supplies contact pilot service. The purpose of the latter is to furnish navigation interests the latest information and advice on channel conditions, and to obtain their views on navigation needs.

Drainage Channels

Construction by the Federal Government on the project tributary streams began about 1950. Channel-maintenance requirements have therefore been in effect on most portions of the project less than 20 years. The drainage districts, in general, were almost totally unprepared, financially or physically, to prosecute organized maintenance programs immediately following construction. Most of their own channels had been constructed some 30 or more years prior to authorizations for Corps projects. They had expended their funds through bonded indebtedness on construction of the projects. During the Depression of the 1930's, very little tax money could be collected, so practically no maintenance work was done. Many of the drainage districts were slow in getting organized and financed to prosecute any sort of maintenance program. Consequently, on many reaches of the channels, initiation of maintenance took place from 3 to 5 years after construction, by which time neglect of maintenance was apparent. However, during the past 10 years, channel maintenance activities have been accelerated generally, and the indications are that the backlog of deficiencies may be overcome within the next several years.

There is no enabling authority whereby the Corps of Engineers can enforce the requirement for maintenance of levees or channels. No penalties can be assessed for noncompliance. Because of this situation, there has been prosecuted an active continuing program of maintenance promotion through continuing liaison with officials of the local bodies, education, annual inspections, frequent spot inspections, urgency in pressing for correction of deficiencies, furnishing local interests copies of inspection reports, and furnishing technical information on improved methods. These efforts have aided greatly in securing improved project maintenance.

Bank Protection

Revetment or dikes placed as bank protection may become "nonoperative" in consequence of migration of the river channel, which leaves the protection unexposed to attack by the river currents. Operative revetment or dikes may be lost or destroyed by the river, making it necessary to extend, replace, reinforce, or repair the protection. Until the stabilization program became well advanced, such losses in many instances were considerable. However, in recent years, maintenance costs have been greatly diminished, owing to the success of the long-range program. In 1945, the annual maintenance expenditures for standard revetment were 15 percent of the total cost of the 110 miles of operative revetment then in place. Five years later, when 190 miles were operative, the maintenance factor decreased to about 6 percent, and 10 years later when 440 miles were operative, it dropped to about 3 percent. In 1959, a revision in policy resulted in changing revetment reinforcement from a maintenance cost to a project

cost. Expenditures for reinforcement now average about 1 percent of the cost of operative revetment in place, and maintenance has leveled off at about 2 percent. The lowered cost of revetment reinforcement is attributed to the effectiveness of support of one revetment by another, and the result of easing crossovers into the concave bends. However, it is believed now that the total 3 percent factor is not likely to be lowered but will continue to be applicable to revetments after all project construction has been completed.

Recreational Development

Initial impoundment in the Wappapello Reservoir began in the spring of 1941, and during the summer the general public had access to the lake only by means of county roads that had been intercepted by the impoundment. For the next 4 years, visitation to the reservoir was mainly by fishermen, and pleasure boating was limited. The attendance in 1945 was estimated to be about 27,000 visitor-days. After passage of the 1944 Flood Control Act, which by section 4 authorized the Chief of Engineers to construct, maintain, and operate public park and recreational facilities in reservoir areas under the control of the War Department, a master plan for development of the reservoir resources was adopted. It provided for extensive development of two primary areas and limited development of a number of secondary areas. Due to a limitation on funds available for this work, the program was restricted to essentials, including those required to provide boat access to the lake, picnic areas, water supply, and sanitation. In 1957, the Missouri State Park Board leased 1,850 acres of reservoir area for development of a State park. Use of the recreation resources intensified, and the annual attendance increased to 440,000 visitor-days in 1959 and to 1,871,000 visitor-days in 1971. The Missouri Department of Conservation maintains a fish and wildlife conservation program under agreement with the Secretary of the Army. Current operations include continuance of the development of public access areas, maintenance of recreation facilities, and ranger patrol of leased lands to insure compliance with lease agreements.

In the Yazoo Basin, development for recreational use began in the Sardis and Arkabutla Reservoir areas with improvement of the existing access roads and construction of new ones, and installation of limited facilities for the health and safety of the visiting public. The roads provided public access to the shoreline at a minimum number of points. The roads and boat landing ramps were graveled; consequently, the roads were usually dusty and the ramps were destroyed annually by wavewash. The availability of additional funds in 1959 made it possible to provide bituminous surfacing on many access roads as well as concreting of launching ramps. In addition, basic recreation facilities in picnic and camping areas have been expanded, and public access areas have been landscaped. One State park has been provided in the Sardis Reservoir area, and two in the Grenada Reservoir area. In addition, waterfowl management areas have been initiated by the Mississippi State Game and Fish Commission on all four reservoirs. Fishing camps, marinas, restaurants, sales service, and overnight vacation facilities under commercial lease agreements have been developed. Organized camps have also been developed by the Girl Scouts, Boy Scouts, 4-H Clubs, and the Future Farmers of America. Total attendance at the four reservoirs was 1,488,000 visitor-days in 1955 and 3,661,000 in 1960. In 1971, there were 1,235,000 visitors at Arkabutla Reservoir; 2,463,000, at Sardis; 1,037,000, at Enid; and 2,636,000, at Grenada; totaling 7,371,000 visitor-days for the Yazoo headwater reservoirs. Currently, access roads to all parts of the shorelines are being extended and improved, making it possible for an increasing number of people to enjoy the recreation and fish and wildlife resources provided by these improvements. The mode of

operating these reservoirs is favorable to the enhancement of fish and migratory waterfowl populations. The production of vegetation as the flood storages are withdrawn during the summer months, followed by reinundation of vegetation during the winter months, provides both migratory-waterfowl foods and organic matter, which decomposes and furnishes water fertility for the fisheries resource, and also a means for control of turbidity. In addition, forest areas are being managed to salvage merchantable timber endangered by reservoir conditions and to encourage the transition from the original upland species to the types capable of adjusting to the filling and emptying of the reservoir.

Malaria Mosquito Control

Sardis Reservoir, the first of the Yazoo Basin reservoirs to be constructed, was placed in operation in 1940. At that time, malaria was endemic in north Mississippi. Storage of floodwater in the reservoir afforded an ideal habitat for the production of the anopheline mosquito, the vector of the malaria parasite. Arkabutla Reservoir, placed in operation in 1943, added to the public health hazard. Mosquito control measures therefore became necessary. The initial measures taken consisted of manipulating the release of flood storages, and the application of larvicides. The storage releases were planned to provide falling stages for 5 days and rising or stationary stages for 2 days, for the purpose of stranding reservoir flotage on the shore and thereby disrupting the development of the mosquito larvae. The larvicide applications, made weekly, initially included oil or Paris green solutions sprayed over shallow water areas within 1 mile of human habitations, which was taken to be the maximum flight distance of the mosquito from its point of origin. These operations were conducted principally by boat, and the limited amount of clearing at Sardis made them very difficult. The costs of clearing and annual rebrushing to maintain the reservoir areas free of woody vegetation to the 5-year flood frequency elevation would have been excessive. Consideration was then given to the purchase of additional lands in the reservoir area to permit the removal of all human habitations in each reservoir for a minimum of 1 mile from the water's edge. Fortunately, the timely development of the formulation dichlorodiphenyltrichloroethane (DDT) made adoption of this proposal unnecessary. This new larvicide, aerially applied on a weekly basis, also made possible a substantial reduction in clearing. When the herbicide 2,4-D became available, it seemed to offer a means of effective and economical control of regrowth. However, it is hazardous to use near agricultural crops because of its high volatility. Therefore, annual rebrushing near populated areas remained a necessity.

To determine the magnitude of malaria infection in the reservoir areas, the Corps of Engineers, in cooperation with the Mississippi State Board of Health, obtained, each year, blood smears of all inhabitants within 1 mile of the Sardis and Arkabutla Reservoirs. Following World War II, the new malaria control medicines were so effective that the last positive smear was obtained in 1948. In 1951, as laboratory reports continued to be negative, the State of Mississippi agreed to the suspension of all malaria control operations in the reservoirs. Surveillance has continued but no evidence of malaria or other insect-borne disease has since been detected.

At Wappapello Reservoir, the control of lake levels to limit the production of malaria-bearing mosquitoes was initiated in 1943. The plan was to fluctuate the water level about half a foot in 7- to 10-day cycles during the month of May, and then to lower the stage by 3 feet between June and December. Objections from fishermen and other recreational interests caused this plan to be modified in 1954. But after continuance for several years, further objections were received, leading to additional modifications in 1963, which had the concurrence of the Missouri Conservation Commission and the

Division of Health of the State of Missouri. The current plan stipulates maintenance of a stabilized level 2 feet above the conservation weir elevation from 1 April until 1 May, 5 feet above the conservation weir level from 1 May until 15 December, and thereafter lowering the pool to the conservation weir level in anticipation of flood control requirements. Periodic spot checks are made in the reservoir to ascertain if larviciding is needed to assure effective control.

Flood Fighting

The 1928 act and amendments thereto authorized the appropriation of emergency funds for rescue work or repair or maintenance of any flood control work on any tributary of the Mississippi River threatened or destroyed by flood. Activities conducted under these authorizations by the District offices utilize temporary organizations comprising personnel trained in flood fighting techniques. They are mobilized in accordance with a standard plan of operation when dangerous river stages appear to be imminent. Local interest organizations coordinate their efforts with forces of the Corps of Engineers to form a task force whose function is to patrol the line of protection and to supplement or reinforce the flood control structures as necessary to preserve the integrity of the levee system. In particularly critical situations, manpower is supplemented by the use of Army troops and convict labor.

Annually or biennially, at the discretion of the District Engineers, in advance of the usual date of occurrence of the spring rise, the District Engineers schedule flood-fight-planning conferences with local interests. These meetings afford an opportunity for careful review of plans and logistics, and for potential participants to familiarize themselves with their roles in time of flood.

CHAPTER VII. PROJECT COSTS AND FUNDING PROCEDURES

Authorizations

Improvement of the Mississippi River and its tributaries, first adopted as a comprehensive project by the Flood Control Act of 15 May 1928, has been prosecuted under two types of congressional authorizations. One of these is provision in the authorization act for construction of a specific plan of improvement, thereby incorporated in the comprehensive project. The other is a monetary authorization covering sums to be appropriated in future appropriation acts. Generally, the authorization of an improvement has included authority to appropriate an amount equal to the estimated cost at the time of authorization. However, in some instances, a plan of improvement has been fully authorized, but the monetary authorization has been restricted to an amount less than the estimated cost, thus permitting only partial accomplishment pending further authorization by Congress. A third category of monetary authorizations includes those by which funds are authorized to be appropriated to provide for increased costs of construction.

Cost Changes

The monetary authorizations included in the Flood Control Acts of 1946, 1950, 1960, and 1965 (as amended by the 1966 act) fall into the third category. Increases made under the 1946, 1950, and amended 1965 acts were applicable to the comprehensive project as a whole, permitting distribution to any authorized feature of the project. These acts extended the flexibility permitted by the Flood Control Act of 1941, which removed restrictions on the cost of individual parts or features of the project by providing that "* * * any appropriations heretofore or hereafter made or authorized for said project as herein or heretofore modified may be expended upon any feature of the said project, notwithstanding any restrictions, limitations, or requirements of existing law * * *." The 1960 increase covered only channel improvements on the main stem. The principal increases in cost enumerated in the 1965 act included the channel improvement feature, where the prior estimate was reevaluated to reflect estimated costs of work deemed necessary to be proscecuted for the ensuing 10 years; the main stem levee features, for provision of additional stability measures; the south bank Red River levee feature, for levee protection measures; the Atchafalaya Basin feature, for provision of adequate flood-carrying capacity; and the Boeuf-Tensas-Macon Basin and the Yazoo headwater area, for provision of adequate drainage outlets. Besides updating the authorized plan of improvement to reflect current conditions and price levels, the 1965 act made monetary authorization applicable to additional work needed to make the project more effective. The $97,000,000 authorized by the "River Basin Monetary Authorization Act of 1971" was an addition to previous authorizations for prosecution of the comprehensive plan of development for the Mississippi River and Tributaries Project.

Budgeting and Accounting

In 1950, the Commission on Organization of the Executive Branch of the Government advocated a general overhaul of Federal fiscal procedures, in the belief that many of the accounting methods then controlled by earlier legislation were outmoded due to the tremendous growth of the Government in the preceding 30 years. Acting in response, the Congress enacted the Budgeting and Accounting Procedures

Act of 1950, which provided for setting up an accounting system incorporating sound commercial and governmental practices and providing better controls over all Federal funds. Conforming to this act, the Mississippi River and Tributaries Project was administratively subdivided into major functional areas termed "Projects" and "Separable Units." However, the act did not modify the status of the project as authorized by Congress in 1928.

The various specific authorizations, together with the administrative distribution of monetary appropriations, have resulted in a complex structure of project and monetary authorizations. Financial data on the project, presented to the Congress annually, show the estimated cost of the individual features, and project and monetary authorizations made or remaining for accomplishment of the authorized project. Initially, the breakdown of the total cost of the comprehensive project and of the original monetary authorization among the many project features was made generally in accordance with the feature breakdown for the project as given in House Document 90, 70th Congress, and as authorized by the Flood Control Act of 1928. A similar procedure was followed in distributing the lump sum authorized in the 1936 Flood Control Act for subsequent appropriation for the project as modified by that act. Thereafter, except for the 1946, 1950, and 1960 acts, previously discussed, the authorizing acts specified the improvements and their estimated costs, and those amounts were added to the authorized costs of the comprehensive project.

Until Fiscal Year 1957, the practice was to report the costs of most individual projects as the original estimated cost, which was also the original monetary authorization specified in the authorizing act. Subsequent adjustments for increased prices were limited to the total amounts provided later for this specific purpose. However, the costs of several of the Federal projects for which the original acts provided only partial monetary authorization were also reported as limited to the original amounts of the initial monetary authorization. Hence, the reported total cost of the comprehensive project equaled the total amount of its monetary authorization until this procedure was changed to meet new budgetary requirements beginning in Fiscal Year 1957. Budgetary data submitted thereafter reflected the full cost of each feature at the time of authorization, with adjustments made for cost increases insofar as practicable without detailed cost studies for all the features of the comprehensive project. The extensive studies forming the basis for the House Document 308 report provided the first opportunity to bring up to date the estimated cost of each project feature to reflect current conditions and price levels.

Table 4 delineates the cost summary of the reevaluated Mississippi River and Tributaries Project under 1972 conditions, and price levels. Table 5 lists the amounts appropriated as of 30 June 1972 for completed units of the project.

Table 4

Mississippi River and Tributaries Project

Estimated Total Federal Cost as of 30 Jun 1972

Item	*1 Jul 72 Prices (thousands of dollars)*	*Total Federal Allocation, 30 Jun 72 (thousands of dollars)*
Main Stem Features		
Mud Lake Pumping Plant	850.0	0.0
Channel Improvement	1,179,000.0	737,751.7
Mississippi River Levees	353,000.0	234,403.4
South Bank Arkansas River Levees	17,000.0	15,676.3
South Bank Red River Levees	25,300.0	9,367.0
Atchafalaya Basin	430,000.0	188,339.0
Old River Control	78,200.0	65,327.0
Completed Separable Units	130,648.1	130,648.1
Subtotal	2,213,998.1	1,381,512.5
Tributary Basins (Flood Control Features)		
Cairo-Mounds-Mound City*		
St. Francis Basin	216,485.0	89,200.2
Cache Basin	59,000.0	915.0
L'Anguille Basin	9,150.0	0.0
Lower White River	30,400.0	12,485.7
North Bank Arkansas River Levees	10,800.0	7,049.4
Grand Prairie Region	51,700.0	0.0
Bayou Meto Basin	21,600.0	0.0
Boeuf-Tensas-Macon Basin	99,100.0	27,898.0
Red River Backwater Area	56,900.0	14,496.0
Bayou Cocodrie and Tributaries	8,500.0	3,423.6
West Kentucky Tributaries	4,390.0	255.0
Reelfoot Lake-Lake No. 9, Tennessee-Kentucky	3,000.0	439.4
West Tennessee Tributaries	26,400.0	8,649.0
Wolf River**	0.0	0.0
Memphis Harbor**	0.0	0.0
Yazoo Headwater Area	229,426.0	126,212.3
Yazoo Backwater Area	46,827.0	17,253.0
Big Sunflower Basin	24,874.0	12,945.3
Steele Bayou Basin	5,500.0	29.7
Greenville Harbor**	0.0	0.0
Vicksburg Harbor**	0.0	0.0
Baton Rouge Harbor	6,000.0	699.2
Amite River†	0.0	0.0
Lake Pontchartrain††	0.0	0.0
Teche-Vermilion Basin	9,880.0	422.0
Eastern Rapides and South Central Avoyelles	24,800.0	100.0
Section 6 Levees	4,000.0	3,744.9
Completed Separable Units	34,085.1	34,085.1
Subtotal	982,817.1	360,302.8
Specific Fish and Wild Life Improvements		
St. Francis Basin	1,515.0	124.8
Yazoo Headwater Area	74.0	0.0
Yazoo Backwater Area	73.0	0.0
Big Sunflower Basin	226.0	0.0
Mississippi Delta Region	9,100.0	153.0
Subtotal	10,988.0	277.8
Grand Total	3,207,803.0	1,742,093.1‡

* Included in Mississippi River Levees project feature.
** Project completed, included under "Compieted Separable Units."
† Work accomplished by local interests; no longer required.
†† The portion completed under MR&T is included under "Completed Separable Units."
‡ Includes $4,332.0 FY 71 budgetary reserve allotted 1 Jul 71.

Table 5

Flood Control, Mississippi River and Tributaries, Completed Units as of 30 Jun 1972

		Amount Appropriated (in thousands of dollars)
Main Stem		
Miscellaneous Units:		
Surveys, gages, and observations expended prior to 1941	7,233.9	
Impounded savings	1,593.1	
Section 10 surveys	4,995.2	
Operating fund, WES	874.0	
OCE services prior to 1941	19.2	
Transfer to revolving fund, OCE	19.9	
Project-owned plant, transferred to revolving fund	24,924.6	
Alluvial Valley mapping	4,094.3	
Subtotal Miscellaneous		43,754.2
Channel Improvement:		
Contraction works	11,923.9	
Subtotal Channel Improvement		11,923.9
South Bank, Arkansas and Red Rivers:		
Channel realignment, Arkansas River	125.1	
Subtotal South Bank, Arkansas and Red Rivers		125.1
Mississippi River Levees:		
Roads on levees	658.9	
New Madrid Floodway	6,521.6	
Eudora Floodway	826.2	
Boeuf Basin levees	2,764.6	
Grants Canal	7.1	
Bonnet Carré spillway	14,212.2	
Morganza structure	18,192.4	
Subtotal Mississippi River Levees		43,183.0
Atchafalaya Basin Floodway:		
Atchafalaya River and Basin	3,375.5	
Wax Lake Outlet and Charenton Canal, Louisiana	10,098.8	
Morganza Floodway other than structure	17,799.7	
Right-of-Way and flowage, Bayou Des Glaises	387.9	
Subtotal Atchafalaya Basin Floodway		31,661.9
Total Main Stem		130,648.1
Off Main Stem		
Lower White Basin:		
DeValls Bluff, Arkansas	231.2	
Des Arc, Arkansas	178.9	
Subtotal Lower White Basin		410.1
Tensas Basin:		
Jonesville	172.9	
Subtotal Tensas Basin		172.9
Harbors:		
Greenville Harbor	2,864.5	
Vicksburg Harbor	4,664.5	
Memphis Harbor	18,736.4	
Subtotal Harbors		26,265.4
Lake Pontchartrain		5,513.1
Wolf River and Tributaries, Tennessee		1,723.6
Total Off Main Stem		34,085.1
Grand Total Completed Works		164,733.2

CHAPTER VIII. PROJECT BENEFITS

The works constructed under the comprehensive Mississippi River and Tributaries Project have prevented general flooding of the valley. They have, in addition, furnished partial protection to large areas not afforded full flood protection; major drainage improvements to considerable areas; and widespread navigation benefits. However, a complete evaluation of the total benefits directly attributable to construction of the project is impossible because of the difficulty of accurately reflecting all of the benefits of a complex project encompassing so great an area.

Likewise, no method has been developed to assign flood control benefits separately to each of the features that combine to produce them, although the damages prevented by protecting an area from overflow can be evaluated. Studies of the economic justification of the project have been based primarily on the flood damages prevented by the protective works, benefits due to navigation, and miscellaneous lesser benefits. Estimates of the flood damages prevented have taken into account increased crop production resulting from more intensive use of land, made possible because protection has been assured. The navigation benefits include savings due to increased tonnages resulting from the improved navigation channel. Miscellaneous benefits consist mainly of savings due to reduction in requirements for levee setbacks; in the amount of emergency measures, in the quantity of maintenance dredging, in damage to riverside facilities, and in the extent of flood fighting. Fish and wildlife losses and benefits are also taken into consideration in the analysis when pertinent. Additionally, the project produces many intangible benefits to the region and to the Nation on which specific values cannot readily be placed. The main-stem levee and channel improvements, or any portion of them, are not susceptible of separate economic analyses. The only practicable method of making an economic analysis is to evaluate total direct benefits for comparison with total costs of work.

Records maintained since 1928 include the cumulative flood damages prevented by the project. Estimation of these damages takes into account the area flooded in 1927 and the area that would have been flooded during subsequent high water periods if the levees had not been restored after the 1927 flood. Such flood damages prevented in the 42-year period of 1928 to 1971 are estimated to total \$8.8 billion, based on the state of development and price index at the time of occurrence. Included are damages prevented to crops and capital improvements, such as homes, businesses, roads, bridges, and utilities. This figure will obviously increase in the future with increased clearing and development of the formerly flooded and inadequately drained areas.

It is estimated that the tonnage of waterborne commerce on the lower Mississippi River between the mouth of the Ohio River and Baton Rouge has multiplied more than 19 times since 1928. The navigation benefits attributed to the Mississippi River and Tributaries Project are taken to be the savings to shippers using the waterway, estimated to total about \$4.5 billion for the period of 1928 to 1971. This reach is the basic component of the extensive inland waterway system that has assured the benefits of low-cost transportation to domestic and international trade.

Miscellaneous benefits, previously described, have been estimated to total \$0.5 billion for the period of 1928 to 1971.

Thus, defined in these restrictive terms, the combined cumulative project benefits are on the order of \$13.8 billion, excluding such secondary benefits as prevention of loss of life, protection of health and welfare, and security. Considering the total amount of nearly \$2.1 billion expended on the project from 1928 through 30 June 1971, it is apparent that the project has returned about \$6.00 for every dollar of cost to date. This approach to the project benefits does not attempt to evaluate the regional

development factor. Neither facts nor figures are available to permit making a quantitative estimate of what the economy of the region might have been today in the absence of the project. Comparisons of the 1929 and current figures concerning population, income, and employment for the lower Mississippi region point up an impressive record of growth. Certainly, much of this growth must be attributed to the increased confidence and opportunities assured by the project. The extent of this growth in investments of capital and human endeavor directly attributable to the project is necessarily speculative. However, the increased regional development that has resulted from substantial elimination of the flood threat and improvement of navigation is believed to be the most important project benefit to the region and to the Nation.

CHAPTER IX. PLANNING FOR THE FUTURE

Subsequent to adoption of the project in 1928, the Mississippi River Commission proceeded with surveys and reports under the project and those called for by congressional or departmental directives as required. The first inclusive review followed adoption of a resolution of the Committee on Public Works of the U. S. Senate on 12 June 1954, calling for examination and review of the project "as one comprehensive whole and in its entirety." The report of the Commission dated 18 December 1959 summarizing the studies made under this authorization and printed as House Document 308 was titled "Comprehensive Review of the Mississippi River and Tributaries Project." The primary purpose was to review the adequacy of the authorized plan as it had evolved over a period of more than 30 years. In that time, many advances had been made in the science of meteorology, and considerable data had been collected and analyzed concerning great storms and the amounts of precipitation likely to fall on the watershed from probable sequences of large storms. Extensive developments of storage reservoirs and other works of man throughout the entire basin of the Mississippi River and its tributaries had modified the amount and timing of runoff reaching the main stream. Improvements in channel conditions, including the channel cutoffs, made studies necessary to ascertain if the established levee grades were adequate. Recognizing that future population growth, together with increased demands for agricultural lands, is likely to generate interest in protection of lands flooded by backwater or given partial protection by backwater levees with fuseplug sections, the study considered the extent to which such areas could be relieved of flood servitude and developed for other uses without imperiling the flood control plan. The study recognized that economic development in the Alluvial Valley had led to increased demands for water for domestic, industrial, and agricultural uses, and to reduction of areas suitable for fish and wildlife conservation. Consideration was therefore given to the extent to which available flows in the river might be drawn upon to serve various water uses, and to practicable means of conserving the fish and wildlife resources.

Since this study was completed in 1959, there has been a greatly intensified concern, nationwide, in all aspects of water resources development. One manifestation of this heightened interest was passage of the Water Resources Planning Act of 1965, under authority of which the Water Resources Council was established. Responsibilities assigned to the Council include encouragement of the conservation, development, and utilization of water and related land resources of the United States on a comprehensive and coordinated basis by the Federal Government, States, localities, and private enterprise with the cooperation of all affected Federal agencies, States, local governments, individuals, corporations, business enterprises, and others concerned. The Council has initiated a number of comprehensive studies, to be made in accordance with principles, standards, and procedures for Federal participation established by the Council. One of these studies is of the lower Mississippi region, which as delineated by the Council includes the area embraced by the Mississippi River and Tributaries Project and some added areas. This regional study has two primary objectives. The first is to project the needs for water resources development for hydroelectric power, water supply, flow regulation, pollution abatement, recreation, fish and wildlife conservation, flood control, navigation, and irrigation to the year 2020. The second is to develop a program that will meet the unsatisfied needs and to formulate a list of feasibility studies required to implement the program. The features of the program are to be described in such general terms as acre-feet of storage, miles of channel improvement, and acres of water surface. Specific projects will not be identified. Cost estimates will be made of sufficient accuracy to indicate the magnitude of the investment contemplated. No benefit or economic analysis is to be made, but a priority will be recommended for

those feasibility studies required to satisfy needs for the next 15 to 20 years. The study is being directed by a coordinating committee comprising representatives of eight Federal departments and seven States. The Federal representatives include the Departments of Agriculture; Army; Commerce; Interior; Health, Education, and Welfare; Housing and Urban Development; and Transportation, and the Federal Power Commission. The State members represent Arkansas, Illinois, Kentucky, Louisiana, Mississippi, Missouri, and Tennessee. The committee chairman is the President of the Mississippi River Commission. The plan is to develop at least one program for each of the primary objectives, including national efficiency, regional development, and environmental quality. Projections of water requirements for the national efficiency objective will be based on the assumption that the region will continue to grow at the same rate in relation to the national growth rate as it has in the past. For the regional development approach, the program to be formulated will be designed to satisfy the water needs that will develop if the region takes advantage of its resources to improve the economy. The environmental quality program will give priority to measures that will preserve and conserve natural resources and make them most enjoyable for public use, and will not be based on economic efficiency. The plans to be considered will include nonstructural measures, such as flood plain zoning, as well as standard measures. It is expected that this report will be completed in 1974.

Water resources planning by the Mississippi River Commission has been expanded to enable it to fulfill adequately not merely the flood control and navigation needs, but to respond to expanding social and economic requirements. Project planning and design formerly depended essentially upon specialists in hydrology, hydraulics, geology, soil mechanics, and structural design. That group has now been expanded by adding such disciplines as sanitary engineer, ecologist, biologist, forester, sociologist, economist, and recreation planner. These added specialists are required not only for their contributions to modernization of the project features and functions, assuring that the project will keep abreast of modern technological development, but also to increase their effectiveness in benefiting the standard of living. These specialists will be influenced and guided by the considerable wealth of engineering, economic, and administrative experience gained over the past 44 years on the Mississippi River and Tributaries Project authorized in 1928.

APPENDIX A. PRESIDENTS, MEMBERS, AND SECRETARIES OF THE MISSISSIPPI RIVER COMMISSION

Presidents

Name	Term of Office
Gillmore, Bvt. Maj. Gen. Quincy A.	30 Jun 1879—25 Nov 1882 26 Nov 1884— 7 Apr 1888
Comstock, Bvt. Brig. Gen. Cyrus B.	26 Nov 1882—25 Nov 1884 10 Apr 1888— 3 Feb 1895
Gillespie, Col. George L.	15 Feb 1895—12 May 1901
Stickney, Lt. Col. Amos	13 May 1901—25 Feb 1903
Ernst, Lt. Col. Oswald H.	25 Feb 1903—26 Jun 1906
Sears, Col. Clinton B.	26 Jun 1906—14 Mar 1908
Bixby, Brig. Gen. William H.	14 Mar 1908— 1 Jul 1910 10 Jul 1917—17 Jul 1917 (Acting President) 18 Jul 1917— 9 Dec 1918
Fisk, Col. Walter L.	1 Jul 1910—10 Mar 1911
Rossell, Brig. Gen. William T.	10 Mar 1911— 6 Feb 1912 (Acting President)
Townsend, Col. C. McD.	6 Feb 1912— 8 Jun 1917 9 Dec 1918—15 Feb 1920
Warren, Col. James G.	9 Jun 1917—10 Jul 1917 (Acting President)
Patrick, Col. Mason M.	16 Feb 1920— 1 Mar 1920 (Acting President)
Potter, Col. Charles L.	2 Mar 1920—10 Jun 1928
Burgess, Lt. Col. Harry	1 May 1921—14 Aug 1921 (Acting President)
Jackson, Brig. Gen. Thomas H.	10 Jun 1928—14 Jun 1932
Ferguson, Brig. Gen. Harley B.	15 Jun 1932—31 Aug 1939
Tyler, Brig. Gen. Max C.	1 Sep 1939—31 Dec 1945
Crawford, Maj. Gen. Robert W.	1 Jan 1946—31 Dec 1948
Feringa, Brig. Gen. Peter A.	1 Jan 1949—31 May 1953
Hardin, Maj. Gen. John R.	1 Jun 1953—30 Jun 1957
Carter, Maj. Gen. William A.	15 Aug 1957—26 Jun 1960
Lane, Maj. Gen. Thomas A.	27 Jun 1960—30 Jun 1962
Davis, Maj. Gen. Ellsworth I.	1 Jul 1962—30 Sep 1966
MacDonnell, Maj. Gen. Robert G.	9 Dec 1966—31 Jul 1969
Rollins, Maj. Gen. Andrew P., Jr.	11 Aug 1969— 5 Aug 1971
Noble, Maj. Gen. Charles C.	3 Sep 1971—

Members

Name	Organization/Occupation	Term
Comstock, Col. Cyrus B.	U. S. Army	30 Jun 1879—15 Feb 1895
Harrison, Benjamin (Indiana)	Civilian	30 Jun 1879— 4 Mar 1881
Eads, James B. (Missouri)	Civil Engineer	30 Jun 1879— 4 Apr 1883

Name	Organization/Occupation	Term
Mitchell, Henry	U. S. Coast and Geodetic Survey	30 Jun 1879–30 Jun 1888
Gillmore, Col. Quincy A.	U. S. Army	30 Jun 1879– 7 Apr 1888
Suter, Col. Charles R.	U. S. Army	30 Jun 1879–14 Jan 1896
Harrod, B. M. (Louisiana)	Civil Engineer	30 Jun 1879–12 Mar 1904
Taylor, Robert S.	Civilian	4 Mar 1881–10 Mar 1914
Ferguson, S. W. (Mississippi)	Civil Engineer	21 May 1883–19 Apr 1890
Davidson, George	U. S. Coast and Geodetic Survey	1 Oct 1888–19 Apr 1890
Ernst, Lt. Col. Oswald H.	U. S. Army	15 May 1888– 8 Jan 1894
Whiting, Henry L.	U. S. Coast and Geodetic Survey	10 Jun 1890– 4 Feb 1897
Flad, Henry (Missouri)	Civil Engineer	19 Apr 1890–20 Jun 1898
Stickney, Lt. Col. Amos	U. S. Army	30 Jan 1894–12 May 1901
Handbury, Maj. Thomas H.	U. S. Army	14 Jan 1896–22 Jan 1902
Marindin, Henry L.	U. S. Coast and Geodetic Survey	22 Mar 1897–25 Mar 1904
Ockerson, John A. (Missouri)	Civil Engineer	12 Aug 1898–22 Mar 1924
Adams, Lt. Col. Henry M.	U. S. Army	13 May 1901–27 Sep 1904
Casey, Maj. Thomas L.	U. S. Army	22 Jan 1902–14 Aug 1906
Sears, Lt. Col. Clinton B.	U. S. Army	27 Sep 1904–25 Jun 1906
Richardson, Henry B. (Louisiana)	Civil Engineer	31 Mar 1904–21 Aug 1909
Ritter, Homer P.	U. S. Coast and Geodetic Survey	20 Apr 1904–21 Apr 1919
Lusk, Lt. Col. James L.	U. S. Army	27 Jun 1906– 8 Aug 1906
Rossell, Col. William T.	U. S. Army	8 Aug 1906– 5 Jun 1913
Warren, Col. James G.	U. S. Army	14 Aug 1906–22 Nov 1919
West, Charles H. (Mississippi)	Civil Engineer	5 Feb 1910– 7 Jun 1933
Townsend, Col. C. McD.	U. S. Army	10 Mar 1911– 8 Jun 1917
Beach, Col. Lansing H.	U. S. Army	5 Jun 1913– 1 Mar 1920
Glenn, Edward A.	Civilian	11 Mar 1914–30 Jun 1923
Faris, Robert L.	Asst Director, U. S. Coast and Geodetic Survey	23 Aug 1919– 5 Oct 1932
Patrick, Col. Mason M.	U. S. Army	22 Nov 1919– 1 Mar 1920
Burgess, Col. Harry	U. S. Army	1 Mar 1920–20 Aug 1922
Deakyne, Col. Herbert	U. S. Army	1 Mar 1920– 9 Sep 1920
Harts, Col. William W.	U. S. Army	9 Sep 1920– 4 Mar 1921
Lukesh, Lt. Col. Gustave R.	U. S. Army	4 Mar 1921–23 Jul 1925
Hoffman, Col. George M.	U. S. Army	26 Aug 1922–20 Feb 1927
Christie, Jerome O.	Civilian	1 Jul 1923–30 Jun 1926
Flad, Edward (Missouri)	Civil Engineer	19 Jun 1924–30 Jun 1950
Kutz, Col. C. W.	U. S. Army	23 Jul 1925–25 Jul 1928
Stipes, John W.	Civilian	15 Jul 1926–20 Sep 1930
Schulz, Col. Edward H.	U. S. Army	21 Feb 1927–26 Jun 1929
Graves, Col. (Ret.) Ernest	U. S. Army	26 Jun 1928– 9 Jun 1953

Name	Organization/Occupation	Term
Bain, Lt. Col. Jarvis J.	U. S. Army	27 Jun 1929–30 Sep 1930
Glenn, Lawrence A.	Civilian	29 Sep 1930–27 May 1933
Spalding, Lt. Col. George R.	U. S. Army	3 Oct 1930–31 Oct 1935
Colbert, Rear Adm. Leo O.	U. S. Coast and Geodetic Survey	22 May 1933–20 Jul 1956
Wilby, Col. F. B.	U. S. Army	11 Nov 1935–31 Oct 1938
Pharr, Harry N. (Arkansas)	Civil Engineer	14 Jun 1935– 3 Nov 1947
Culbertson, Albert L. (Illinois)	Civilian	6 Jun 1935–30 Jun 1954
Powell, Col. R. G.	U. S. Army	1 Nov 1938–30 Jun 1941
Elliott, Col. Malcolm	U. S. Army	17 Jul 1941–17 Jan 1946
Kittrell, Col. Clark	U. S. Army	17 Jan 1946–20 Feb 1950
Pyburn, DeWitt L. (Louisiana)	Civil Engineer	22 Apr 1948–19 Jul 1968
Shingler, Brig. Gen. Don G.	U. S. Army	25 Apr 1950–11 Oct 1952
Salisbury, Eugene F. (Missouri)	Civil Engineer	21 Aug 1950–28 Aug 1965
Vogel, Brig. Gen. Herbert D.	U. S. Army	12 Oct 1952–31 Aug 1954
Holle, Brig. Gen. Charles G.	U. S. Army	28 Sep 1954–12 Sep 1955
Smith, Egbert A. (Illinois)	Civilian	1 Jul 1954–10 Jan 1956
Potter, Brig. Gen. William E.	U. S. Army	28 Sep 1954–25 Jul 1956
Person, Col. John L.	U. S. Army	13 Sep 1955–23 Sep 1956
Berrigan, Brig. Gen. Paul D.	U. S. Army	24 Sep 1956–31 Jul 1957
Seeman, Brig. Gen. Lyle E.	U. S. Army	27 Jul 1956–14 Jul 1958
Bolen, Harry L. (Illinois)	Civilian	2 Aug 1956–20 Sep 1961
Karo, Rear Adm. (Ret.) H. Arnold	U. S. Coast and Geodetic Survey	26 Jul 1956–31 Dec 1966
Galloway, Maj. Gen. Gerald E.	U. S. Army	13 Jan 1958–11 Dec 1958
Barney, Maj. Gen. Keith R.	U. S. Army	12 Dec 1958–19 Sep 1960
Lapsley, Brig. Gen. William W.	U. S. Army	15 Jul 1958– 2 Mar 1961
Shuler, Brig. Gen. William R.	U. S. Army	20 Sep 1960– 6 May 1962
Graham, Brig. Gen. Jackson	U. S. Army	3 Mar 1961–14 Mar 1963
Council, Harold T. (Mississippi)	Civilian	21 Sep 1961–
Dunn, Brig. Gen. Carroll H.	U. S. Army	7 May 1962–22 Sep 1964
Seedlock, Brig. Gen. Robert F.	U. S. Army	15 Mar 1963–30 Oct 1963
Leber, Brig. Gen. Walter P.	U. S. Army	31 Oct 1963–30 Apr 1967
Walker, Maj. Gen. George H.	U. S. Army	23 Sep 1964–23 Aug 1967
Kellogg, Dr. Frederic H. (Tennessee)	Civil Engineer	22 Oct 1965–
Tison, Rear Adm. (Ret.) James C., Jr.	U. S. Coast and Geodetic Survey	1 May 1967–31 Aug 1968
Bradley, Brig. Gen. William T.	U. S. Army	1 May 1967– 9 May 1968
Roper, Maj. Gen. Willard	U. S. Army	24 Aug 1967– 4 Feb 1968 20 Oct 1969–
Cannon, Brig. Gen. C. Craig	U. S. Army	5 Feb 1968–30 Nov 1969
Haug, Maj. Gen. Clarence C.	U. S. Army	11 May 1968–15 Jul 1969
Sessums, Roy T. (Louisiana)	Civil Engineer	31 Jul 1968–

Name	Organization/Occupation	Term
Jones, Rear Adm. Don A.	National Ocean Survey	17 Sep 1968– 1 May 1972
Parfitt, Maj. Gen. Harold R.	U. S. Army	12 May 1970–
Powell, Rear Adm. Adam L.	National Ocean Survey	26 Jun 1972–

Secretaries

Name	Term of Office
Comstock, Col. & Bvt. Brig. Gen. Cyrus B.	19–21 Aug 1879 (Temporary for 3 Sessions)
Leach, Capt. Smith S.	23 Aug 1879– 3 Mar 1885 7 Apr 1887–17 Mar 1888
Turtle, Capt. Thomas	4 Mar 1885– 6 Apr 1887
Lusk, 1st Lt. James L.	18 Mar 1888–31 May 1888
Powell, Capt. Charles F.	1 Jun 1888–15 Oct 1890
Palfrey, Capt. C. F.	16 Oct 1890–30 Dec 1893
Warren, Capt. J. G.	31 Dec 1893–10 May 1894
Zinn, Capt. George A.	11 May 1894–17 Sep 1895
Waterman, Capt. H. E.	18 Sep 1895–26 Oct 1898 (Died)
Patrick, Capt. Mason M.	29 Oct 1898–12 Aug 1901
Howell, Capt. G. P.	13 Aug 1901–22 Apr 1903
Ladue, Capt. William B.	23 Apr 1903–18 Jul 1906 22 Oct 1913–20 Dec 1913
Lukesh, Capt. G. R.	18 Jul 1906–30 Nov 1908
Knight, 1st Lt. C. H.	1 Dec 1908–14 Dec 1910
Potter, Lt. Col. Charles L.	15 Dec 1910–31 Jul 1912
Smith, Maj. Clarke S.	1 Aug 1912–23 Aug 1917
Bixby, Brig. Gen. (Ret.) W. H.	24 Aug 1917–10 Nov 1917
Thomas, E. J.	11 Nov 1917–22 Jul 1919
Bain, Col. Jarvis J.	23 Jul 1919–13 Oct 1919
Willing, Maj. Wildurr	14 Oct 1919–20 Apr 1920
Lyman, Maj. Albert K. B.	21 Apr 1920–26 Jan 1922
Chisolm, Capt. Edward N., Jr.	27 Jan 1922–30 Apr 1926
Hammond, Capt. Charles S.	1 May 1926–30 Jun 1926
Teale, Capt. Willis E.	1 Jul 1926– 9 Jan 1929
Reinecke, Maj. P. S.	6 Feb 1929–12 Sep 1929
Elliott, Maj. D. O.	13 Sep 1929–30 Jun 1932
Oliver, Lunsford E. (Maj.)	1 Jul 1932–12 Nov 1933
Holle, 1st Lt. Charles G.	18–20 Oct 1932 (Acting Secretary)
Twitty, Capt. Joseph J.	13 Nov 1933–30 Nov 1934
Moses, Maj. Raymond G.	3 Dec 1934–30 Jun 1937 20–31 Oct 1934 (Acting Secretary) 1–22 Jul 1937 (Acting Secretary)
Troland, Maj. G. B.	23 Jul 1937– 1 Jul 1940
Bishop, Lt. Col. H. S., Jr.	31 Jul 1940– 1 Nov 1941

Name	Term of Office
Newcomer, Col. F. K.	20–21 Oct 1941 (Acting Secretary)
Fox, Col. Milo P.	4 Nov 1941– 7 Mar 1945
Senour, Charles	14 Feb 1944 (Acting Secretary)
Herman, Col. Fred W.	8 Mar 1945– 4 Jan 1946
Hardin, Col. John R.	5 Jan 1946– 2 May 1946
Harper, Col. James E., Jr.	15 May 1946–18 Nov 1946
Shortle, Robert L.	4–7 May 1947 (Acting Secretary)
Blankenship, Ernest P.	4–7 May 1947 (Acting Secretary) 5–9 Oct 1947 (Acting Secretary)
Cassidy, Lt. Col. William F.	18 Nov 1947–21 Jul 1949
Boucher, Lt. Col. Jeff W.	22 Jul 1949–14 Sep 1950
McCarty, Lt. Col. Roy D.	15 Sep 1950–10 Jul 1953
Mitchim, Col. Charles F.	11 Jul 1953–31 May 1955
Barschdorf, Col. Milton P.	18 Jul 1955–15 Jul 1956
Bronn, Col. Carl H.	16 Aug 1956–27 Jul 1958
Wilby, Col. Langfitt B.	28 Jul 1958–31 Jul 1960
Downing, Col. Ellsworth B.	15 Aug 1960–31 Jan 1963
Galanti, Col. Philip J.	1 Feb 1963–30 Jun 1964
Clema, Col. Joe A.	7 Aug 1964– 1 Feb 1967
Sheffield, Col. Paul R.	15 Feb 1967–30 Jun 1970
Anderson, Col. Ferd E., Jr.	3 Aug 1970–

INDEX